LLNL-PRES-637554

LLNL IE Accomplishments

Presented at the Nuclear Criticality Safety Program (NCSP) Review, 30 May 2013, Washington, DC

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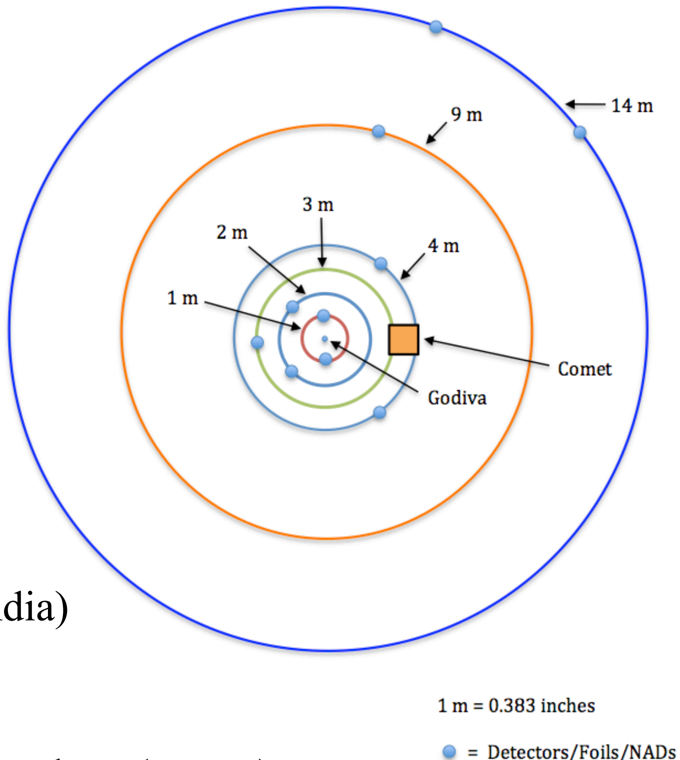
LLNL IE Accomplishments

- IER147 (Godiva Field Reference Values)
  - CED-2 approved
  - NAD Lab established
  - “Live Test” completed
  - Hybrid nTOF spectrometer built and calibrated
  - ^{3}He/Si neutron spectrometer design study completed
- IER148 (Godiva NAD Exercise)
  - NAD and BOMAB stand prototypes Built
- IER184 (TEX)
  - CED-1 approved

IER-147 CED-2 Approved

A variety of instruments will be fielded to measure the neutron and gamma fields:



Steady-State and Pulsed Fields

Photons

- ✓ CaF2:Mn TLDs (Sandia)
- ✓ Falcon 5000 (LLNL)
- ✓ Pocket Ionization Chambers (LLNL) RADCAL-1515 (Sandia)

Neutrons

- ✓ ^{235}U Fission Foils (LLNL)
- ✓ FNADs and PNADs (LLNL); CAD locket (AWE)
- ✓ ROSPEC (LLNL and AWE)
- ✓ CR-39 (LLNL)
- ✓ Bonner Multi-Sphere/Single-Sphere (AWE)
- ✓ NE-213 Proton Recoil (LANL)
- ✓ ^{3}He/BF_3 NRDS (LANL)
- ✓ N-Probe (Sandia)
- ✓ Hybrid nTOF (LLNL)
- ✓ Alpha Box (LLNL)

LLNL is leveraging the expertise and ready-to-deploy equipment of multiple labs

Measurement Objectives

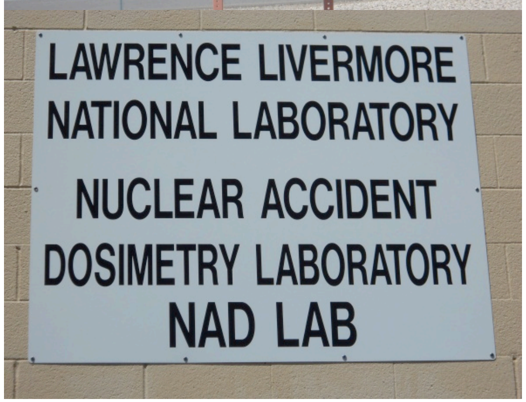
- DOE-STD-1098-2008 requires ± 25% NAD accuracy. Hence, measurements to establish the “reference field” must be much better than this.

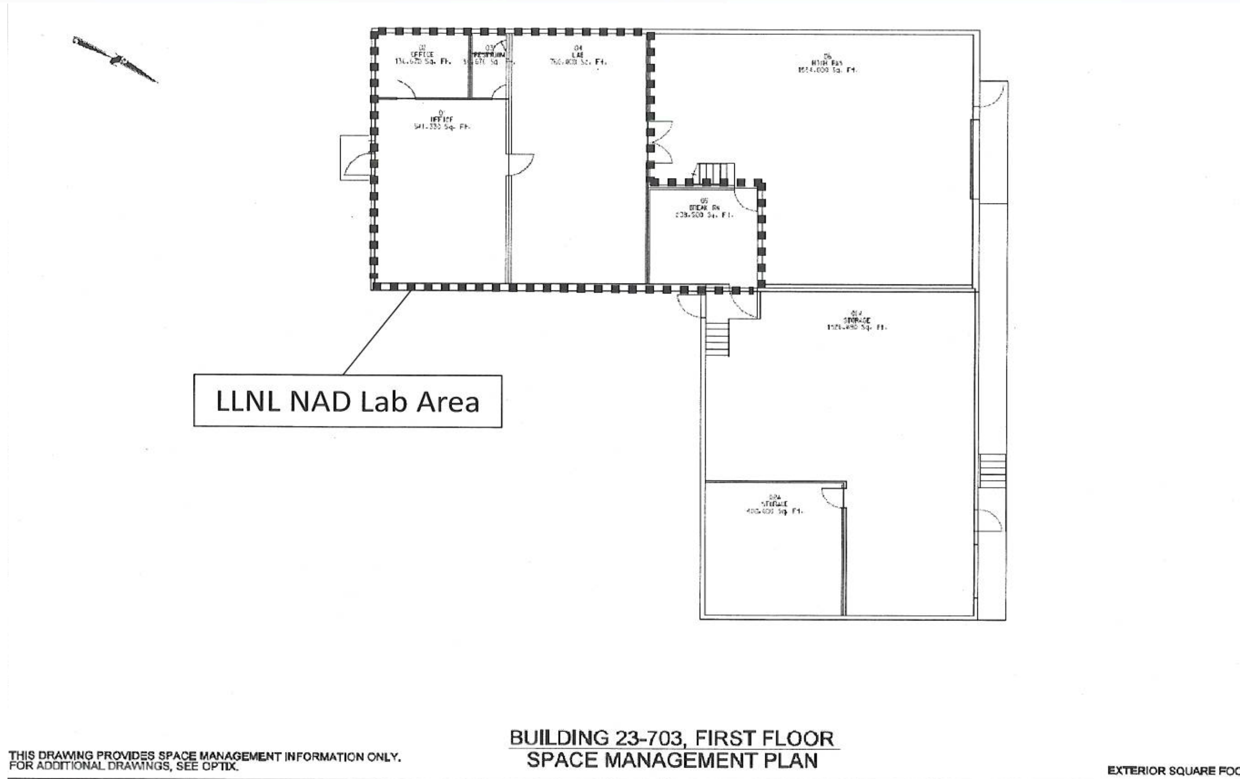
- Instruments chosen are expected to provide ± 10% or better measurements of neutron and gamma fluxes. Combination of multiple instruments and methods provides improved accuracy.

- The Godiva IV fission yield will be determined by ^{235}U fission foil in the glory hole which can be correlated to the external fluxes, temperature rise, and pulse width measured by the other instruments.
  - Scoping calculations for the ratio of Godiva IV fissions to fissions in a ^{235}U foil have been completed by LLNL and ORNL (Thomas Miller) and are in good agreement.

- Current Schedule:
  - Steady-state measurements - weeks of September 9th and 16th
  - Pulsed measurements TBD – pending issue resolution

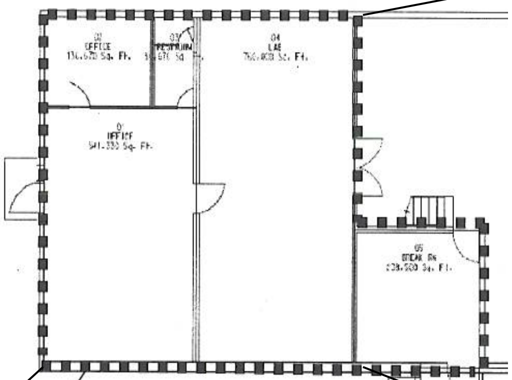
NAD LAB Established





Radiation field and dose measurements in IERs 147 and 148 center around activation measurements of foils and NAD components - necessitating a new LLNL counting laboratory at NNSS. Future uses may include R&D to improved gamma dosimetry methods, develop new methods and new/ standardized NADs, and potential DOELAP use of NCERC.

Refurbished Areas and Equipment

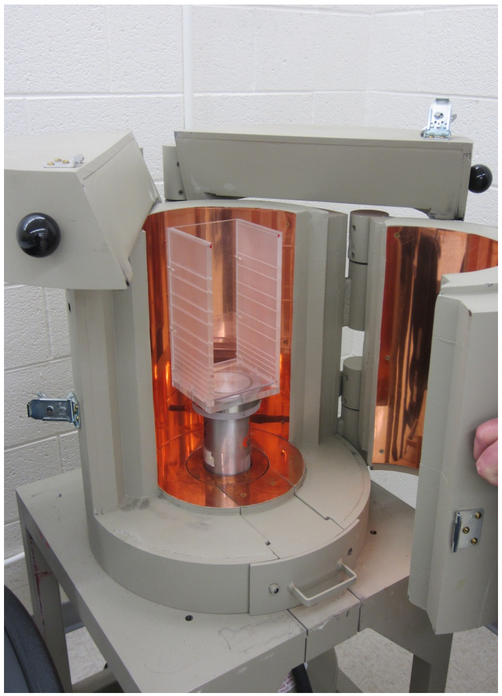


Counting Laboratory with Rolling Lab Benches and Rolling/Adjustable Lead Shielding

Conference Room

Sample Preparation Room with Captairflex XLS714 Ductless Fume Hood

Radiation Measurement Equipment



ORTEC High Purity Germanium Photon Detector with High Performance Low Background Shielding

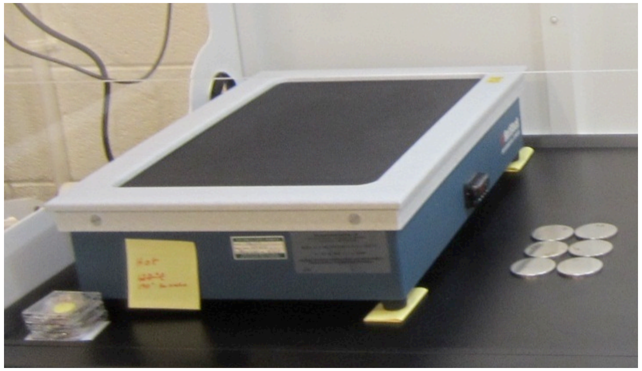
Falcon 5000®
Portable HPGe Based Radionuclide Identifier

iSolo®
Alpha/Beta Counting System

Supporting Equipment

Balance with weight range of 200g to 0.1mg

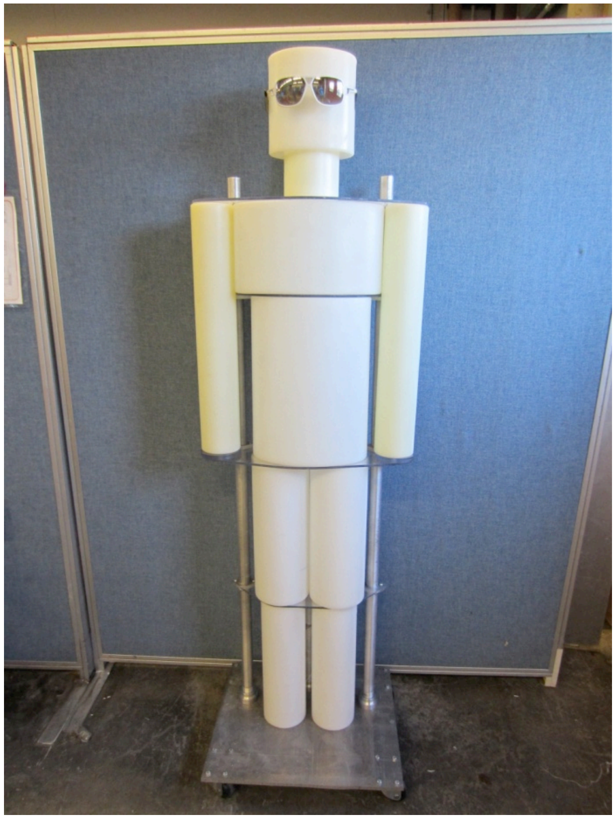
Balance Table



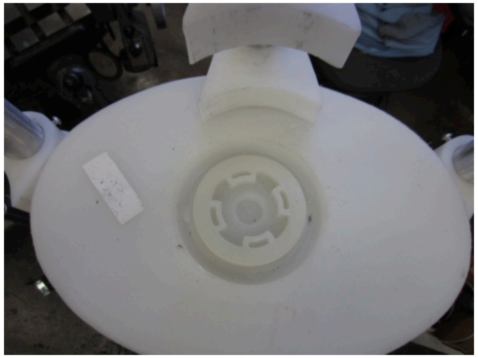
Hot Plate

Static Controlled Lab Chairs

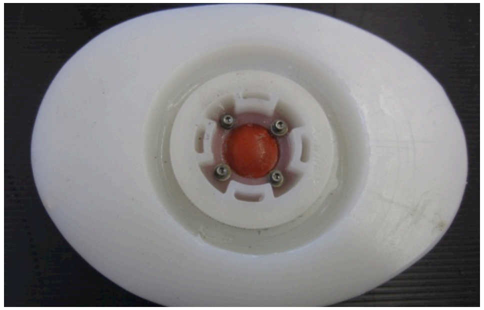
IER-148: BOMAB Phantom and NAD Stand Prototypes



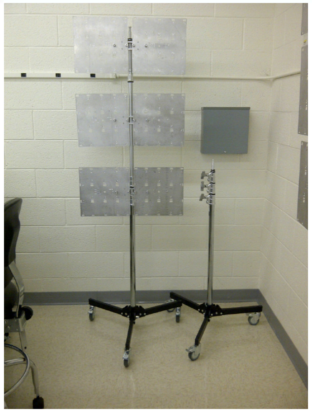
New BOMAB and stand



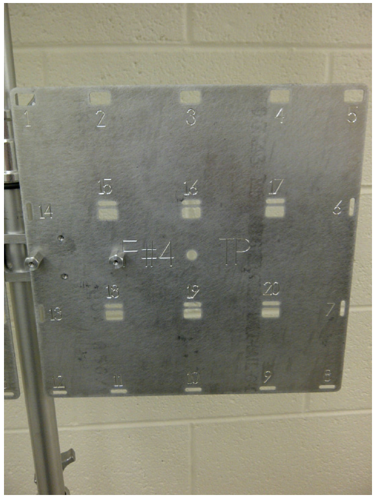
Original closure on phantom sections



New port that allows for removal of liquid sample using a syringe



Prototype of NAD Stand



Individual plate from stand depicting numbering scheme

NAD LAB "Live Operations Test" Completed

Objectives:

- Establish and test site procedures and processes for performing a NAD intercomparisons.
- Demonstrate that the Nuclear Accident Dosimetry Laboratory (NAD LAB) is operational and ready for use during NAD intercomparisons scheduled for 2014.
- Evaluate for possible additional functionalities.

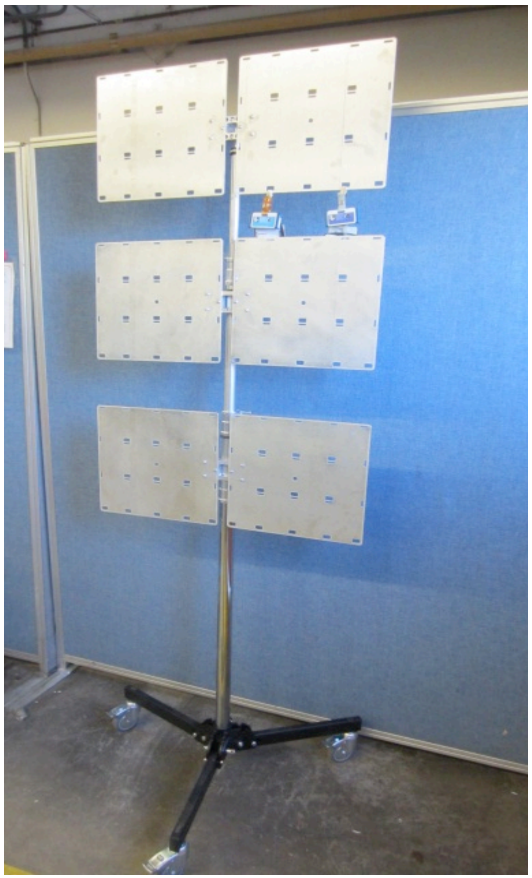
NAD LAB "Live Operations Test" Site Procedures

- Integrated Work Sheet (IWS), NV Radiation Work Permit (RWP), JPNO Activity Level Work Document.
- Required training depending on role and responsibilities: Contamination Control, NTS General Employee Radiological Training, Radiological Worker I, Fire Extinguisher Training, Health Hazards Communication For Supervisors, Beryllium Worker Training Refresher, Lead Awareness, Lead Worker Training, Personal Protective Equipment (PPE) for Non-Laboratory Applications, Pressure Safety Orientation, DOT: Hazardous Waste Transportation, DOT: Basic.
- IWS and Site required safety and monitoring requirements (Dosimeters, Pre-Job briefing, Personnel Protective Equipment, etc).
- Irradiation and transportation procedures.
- Sample preparation and analytical procedures similar to those used at Caliban.

NAD LAB Test Operations

- Preparation of NADs and NAD holder for irradiation
- Segregation of NAD components (after irradiation)
- Weighing NAD components
- Measurement of NAD components
- Crushing, melting and recounting of Sulfur component
- Readout of Personnel Ion Chambers (PICs) gamma dose
- Calculation of neutron dose
- Evaluation of TLD gamma doses
- Dose computations and evaluation
- Other Functionalities Test:
  - Feasibility of alternate dose methods such as the Track Analysis Systems Limited(TASL) – Cr-39

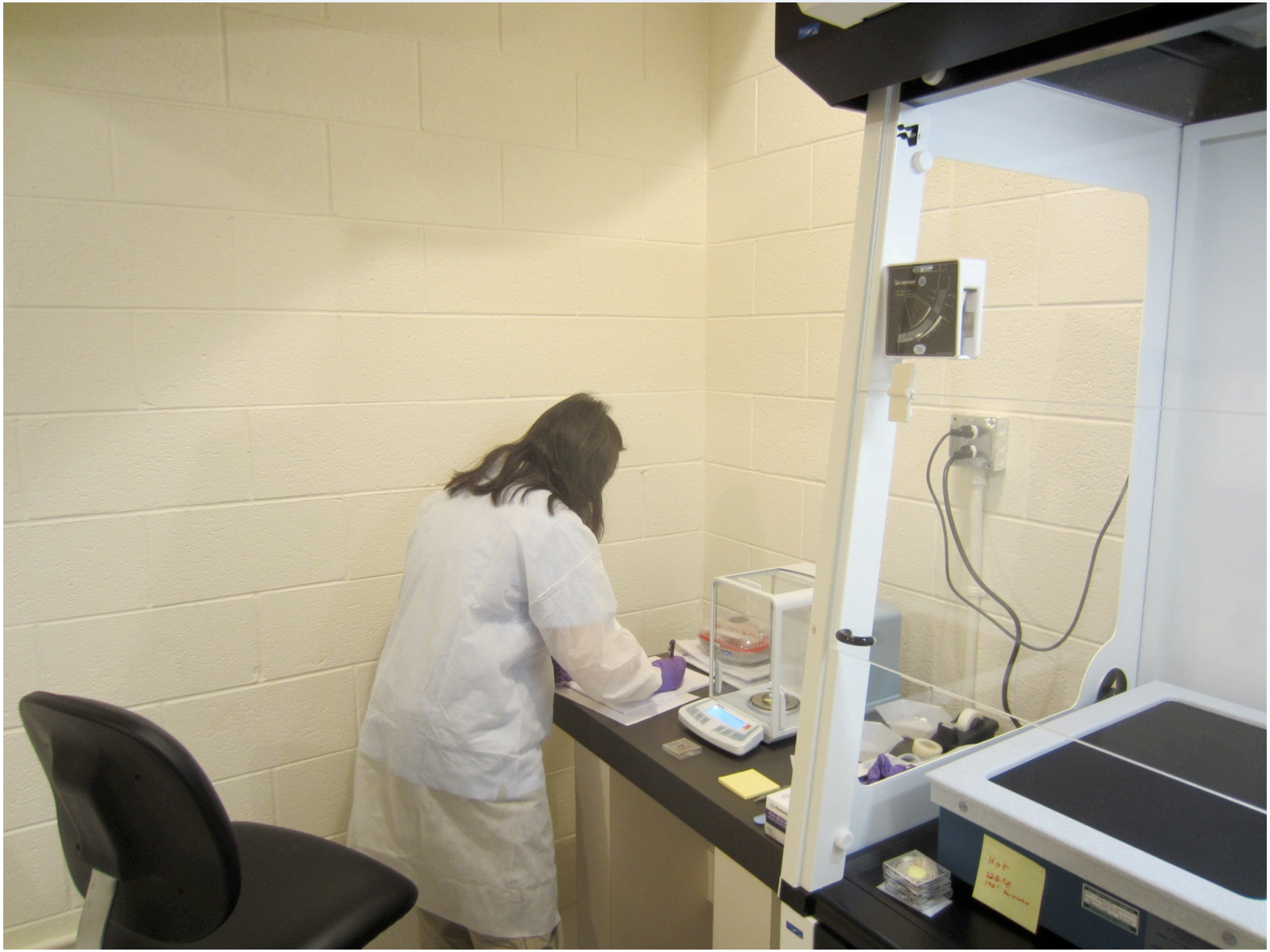
Preparation of NADs and NAD Holder for Irradiation



Note: PNADs included CR-39

Segregation of NAD Components

Weighing NAD Components



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Measurement of NAD Components

Crushing, Melting and Recounting of Sulfur Component

Calculation of Neutron Dose

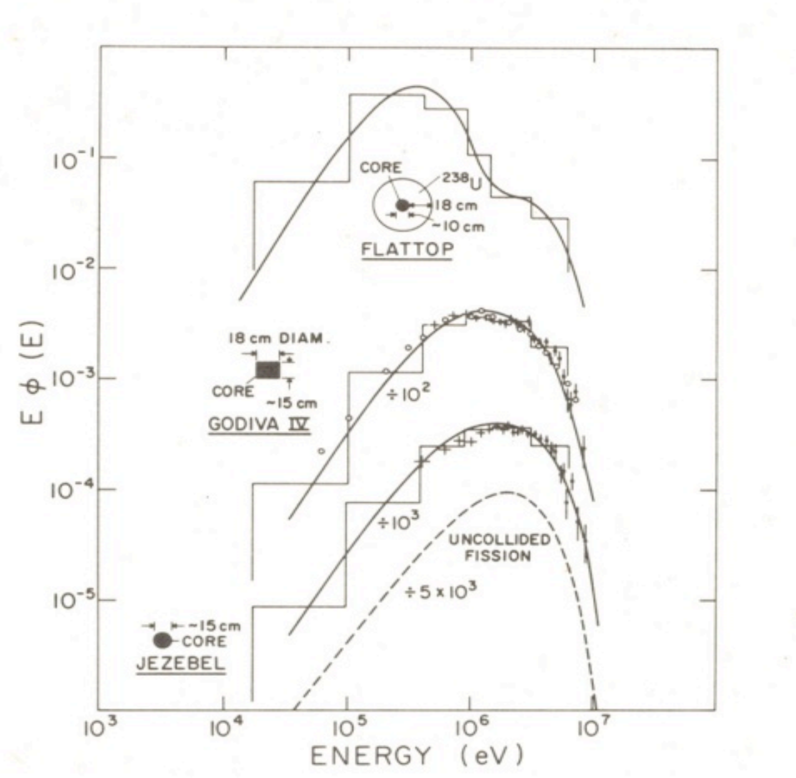
:

PNAD and FNAD average neutron fluence in n·cm^{-2}(and dose results in rads) as a function of energy

	>3MeV	1 – 3 MeV	1 eV – 1 MeV	Thermal	Total
Average	4.89×10^{9} (26)	3.30×10^{10} (112)	3.49×10^{11} 279	9.36×10^{9} (0.70)	3.97×10^{11} (418)
Percent of Total	1.2% (6.2%)	8.3% (27%)	87% (66%)	2.4% (0.2%)	

	>3 MeV	0.9-3 MeV	0.1 MeV – 1 MeV	0 – 0.1 MeV
Historical Flattop Neutron Leakage	2.18%	8.76%	78.1%	11%

Historical Neutron Energy Flux



Evaluation of TLD Gamma Doses

Gamma doses determined from DOELAP Accredited Panasonic 810 dosimeters:

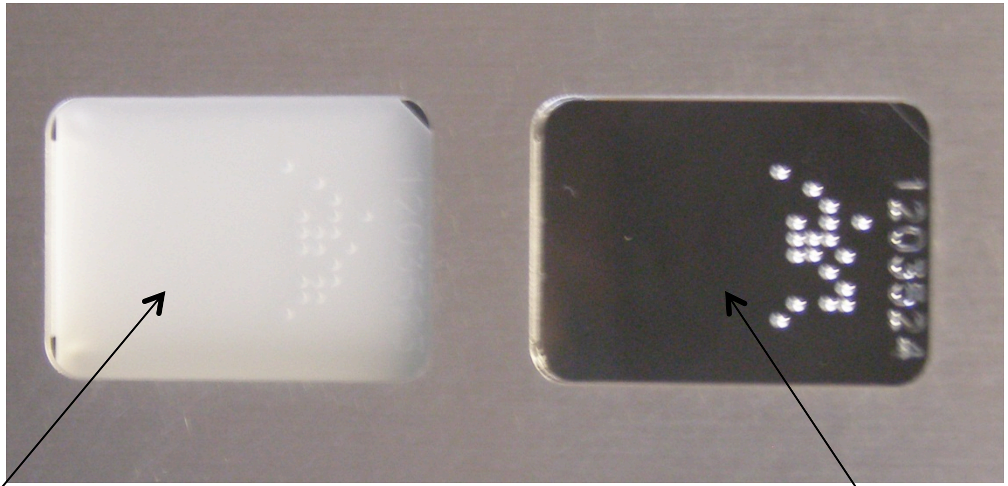
ID	Deep Gamma Dose (R)	Shallow Gamma Dose (R)	Total Gamma Dose (R)
5227	56.1	18.8	75.0
5710	7.00	6.41	13.4
7034	23.6	10.3	33.9
34140	48.5	48.6	97.1
12087*	0	0	0
12757*	0	0	0
34140*	0	0	0

* background dosimeter

First "live" test of procedures and equipment at the NAD Lab in NNSS was a huge success thanks to the teamwork of LANL, NSTec, JLON, and LLNL personnel.

Other Functionalities for the NAD LAB

- Improve Gamma Dosimetry Methods in NADs
- DOELAP use of the National Criticality Experiment Facility?
- Development of new style NADs
- Feasibility of alternate dose methods such as the Track Analysis Systems Limited(TASL) – Cr-39



After exposure to high dose (Flattop)

Typical low dose exposure

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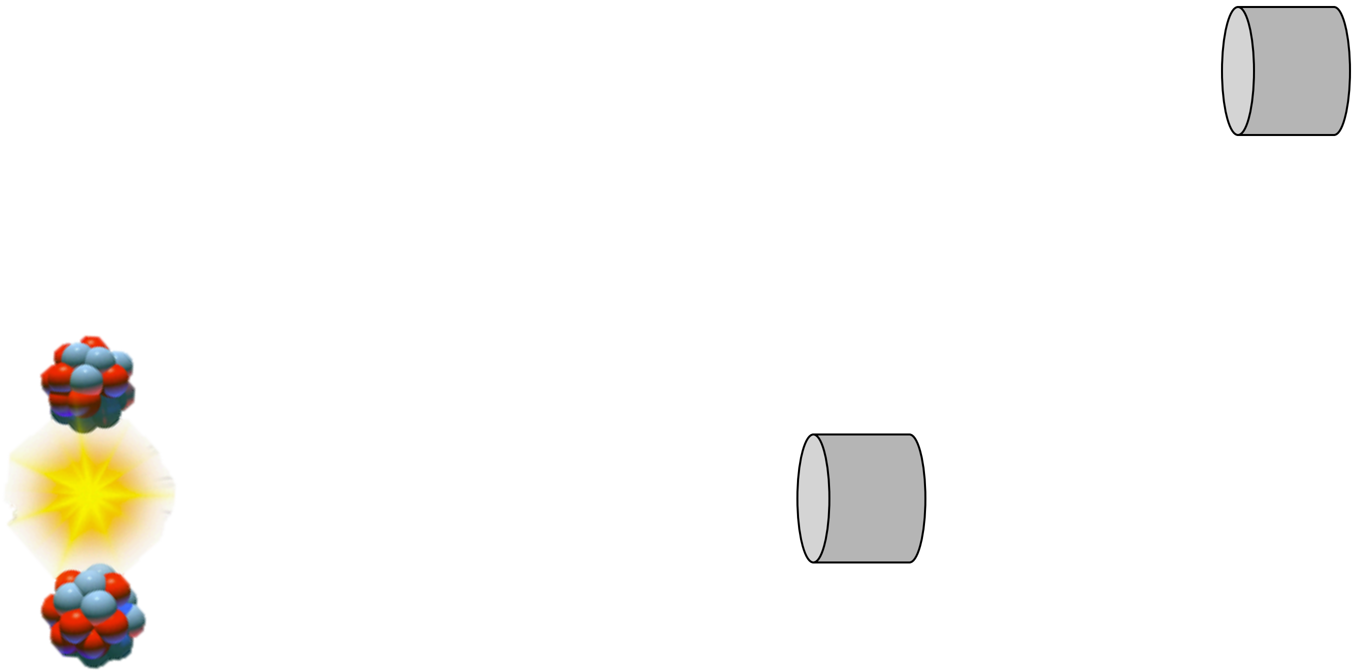
Hybrid nTOF and ^{3}He/Si Neutron Spectrometers

Nathaniel Bowden
Lawrence Livermore National Laboratory

Hybrid nTOF Spectrometer

- **Goal:** Provide direct event-by-event neutron spectroscopy
- **Operating Principle:** Require a single neutron to interact in two separated Liquid Organic Scintillator Detectors



Hybrid nTOF Spectrometer

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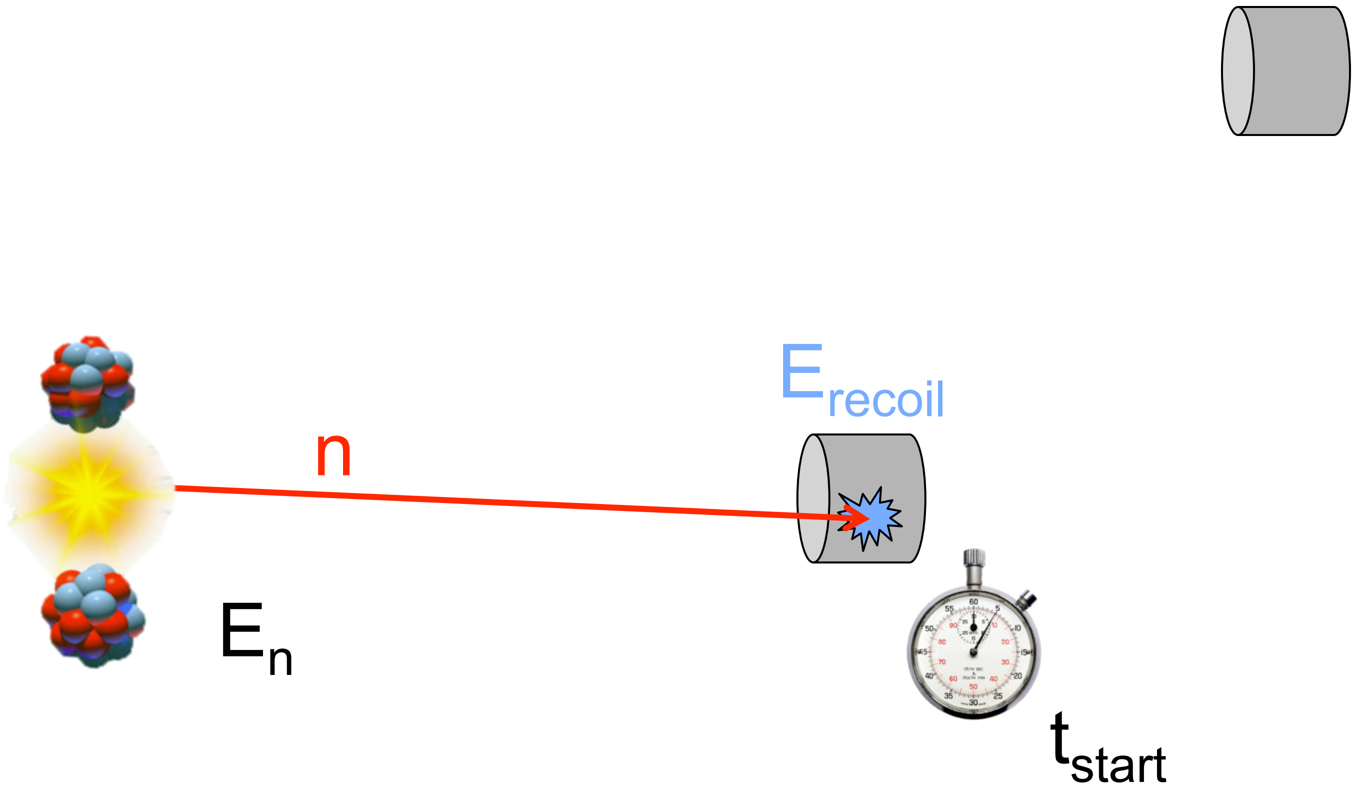

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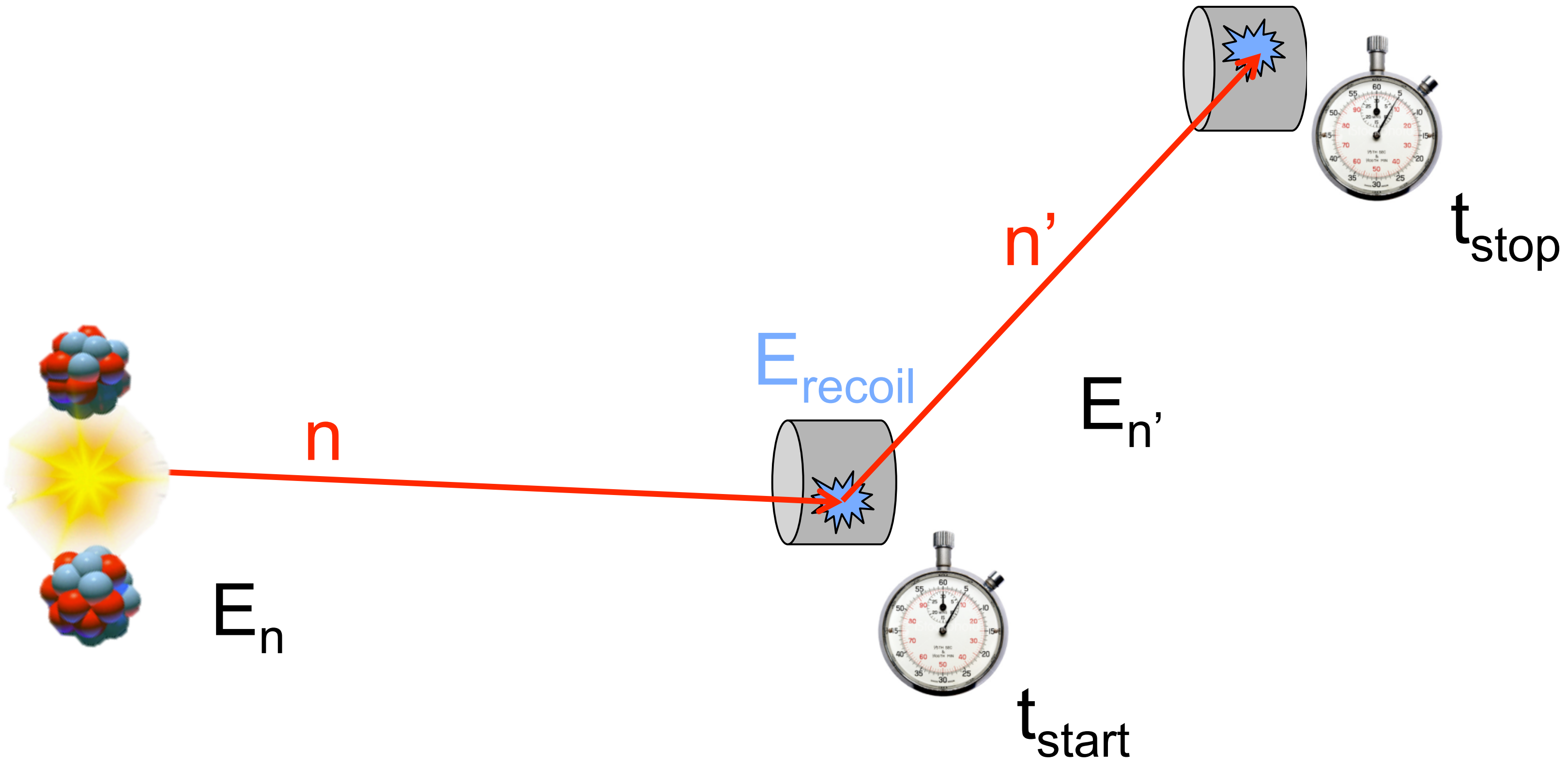

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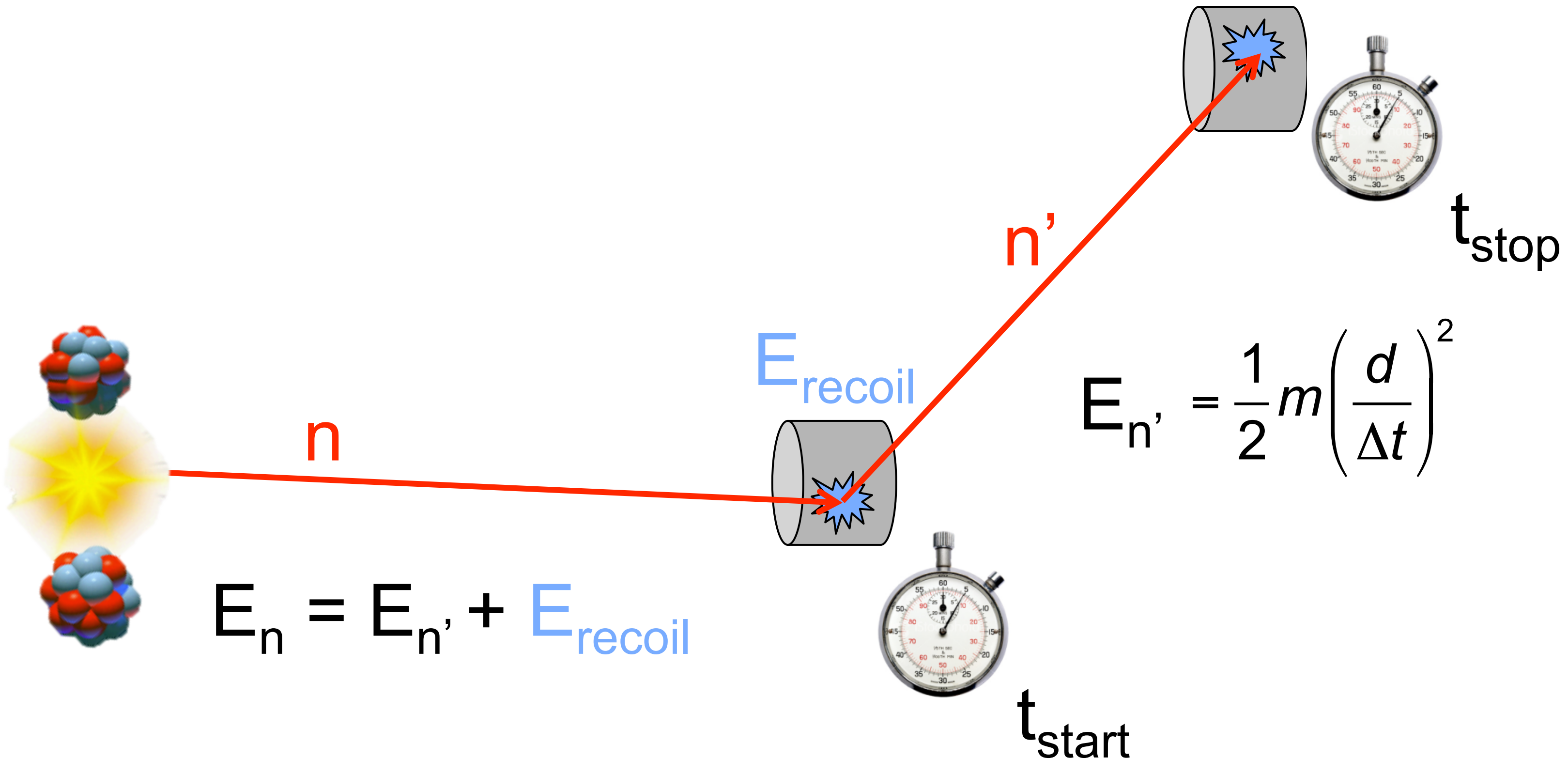


$$E_n = E_{n'} + E_{recoil}$$

$$E_{n'} = \frac{1}{2} m \left(\frac{d}{\Delta t} \right)^2$$

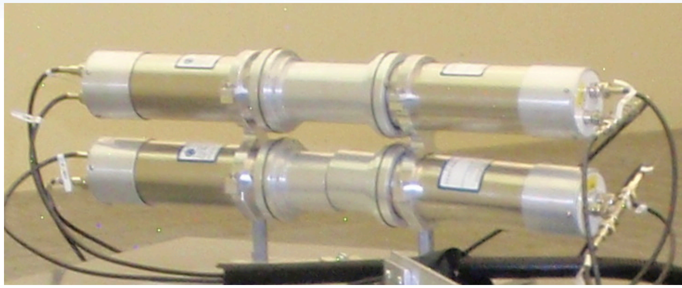
Key Features of this Approach

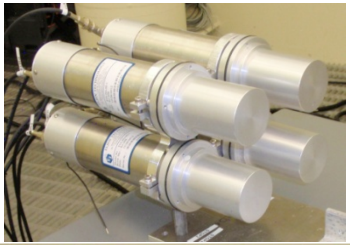
- Advantages:
  - Total energy of each interacting neutron is directly measured
  - Response function is closely approximated by simple Gaussian function at each energy
  - Good gamma ray rejection provided by use of Pulse Shape Discrimination and timing coincidence requirement

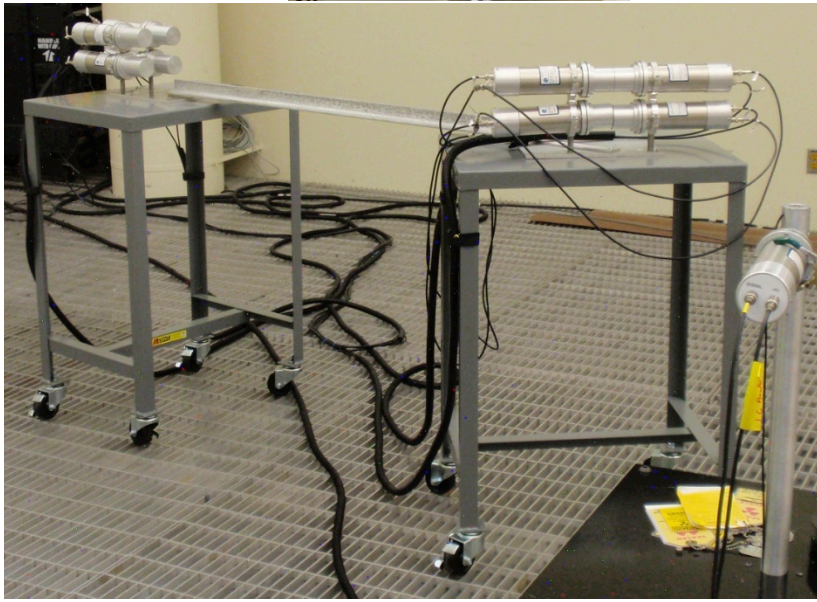
- Disadvantages:
  - Low energy threshold is ~ 1MeV, defined by:
    - scintillator light yield for recoil protons
    - requirement for two scatters
  - Relatively low efficiency to single scatter recoil spectrometers

Hybrid nTOF Spectrometer Implementation

- Start Recoil Detectors (x4)
  - 2” right cylinders of EJ-309 Liquid Scintillator (High flash point, low chemical toxicity)
  - Sized so that double scatter unlikely
- Stop Recoil Detectors (x4)
  - 2” x3” cylinders of EJ-309 Liquid Scintillator
- Neutrons can interact in any start-stop pair
  - efficiency scales as $(N_{det})^2$
- Mean Start-Stop scattering angle ~45^o
- Mean Start-Stop separation ~ 1.5m



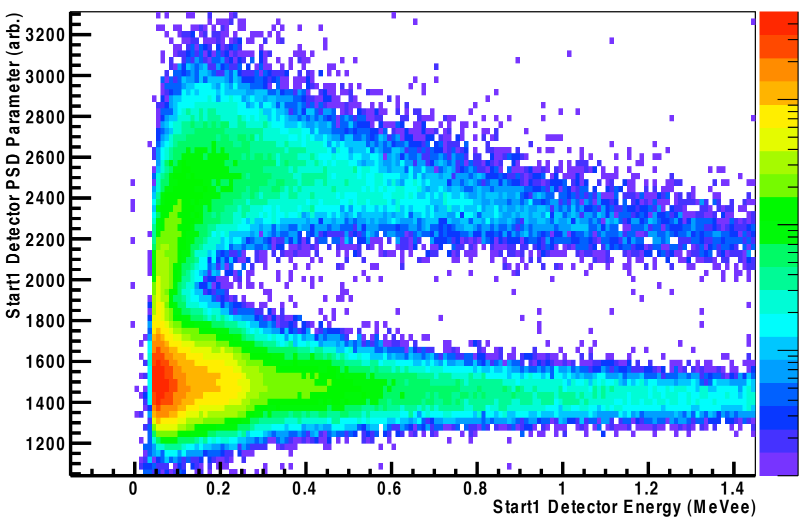


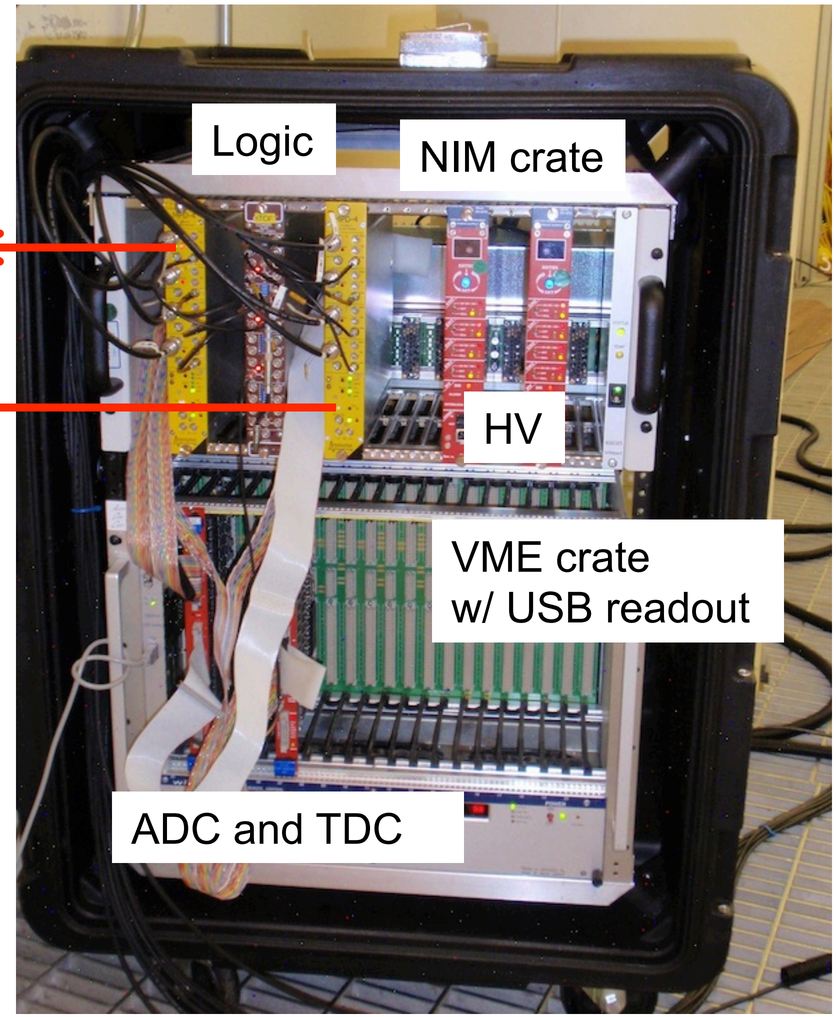


Hybrid nTOF Spectrometer Implementation

- Electronics fully contained in sparsely populated half height rack

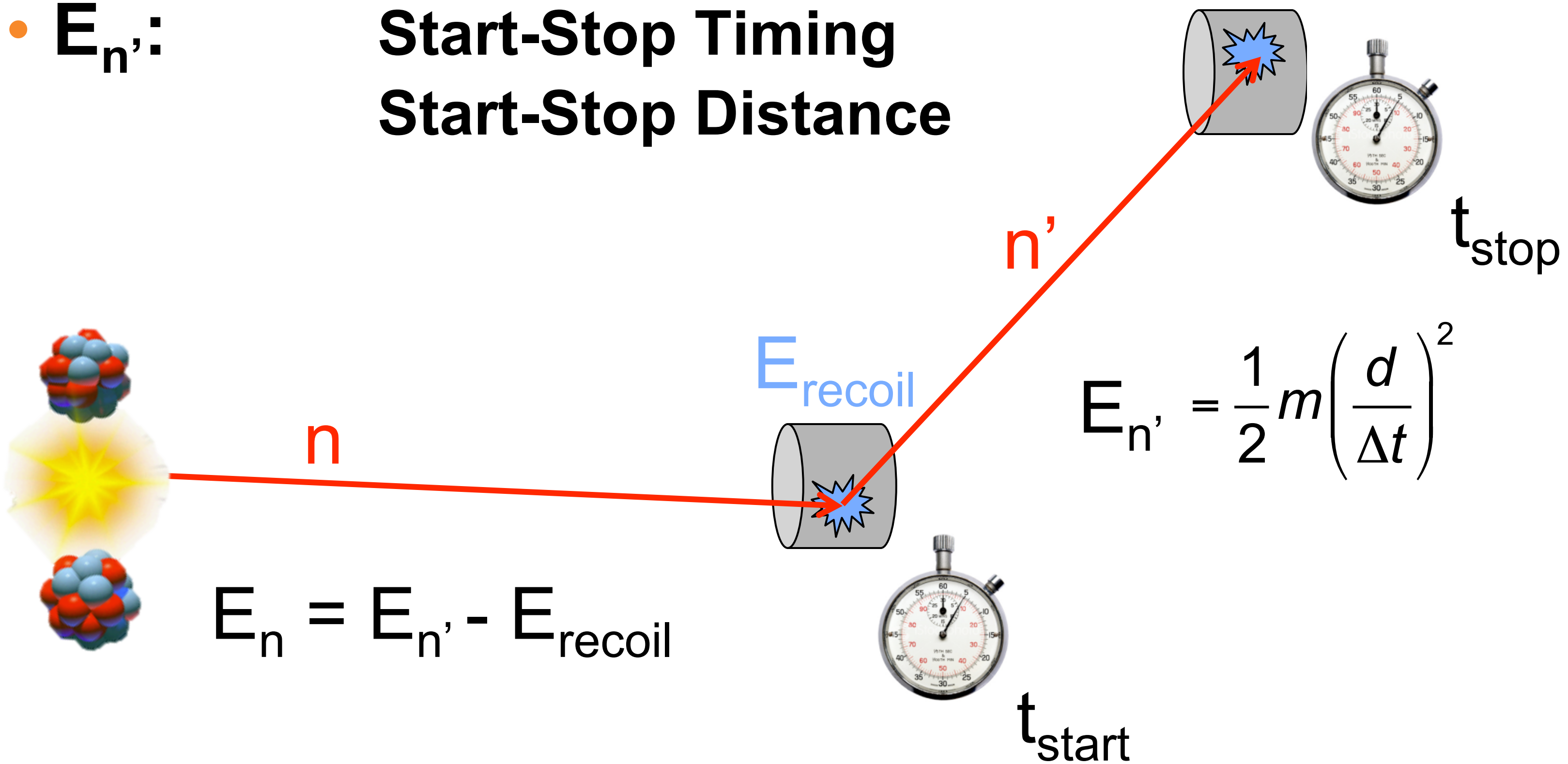
- MPD4 analog PSD module provides:
  - shaped Energy and PSD signal
  - discriminator outputs for timing and triggering





Required Calibrations

- E_{recoil}: Electron Energy Scale
  Proton light yield
- $E_{n'}$: Start-Stop Timing
  Start-Stop Distance

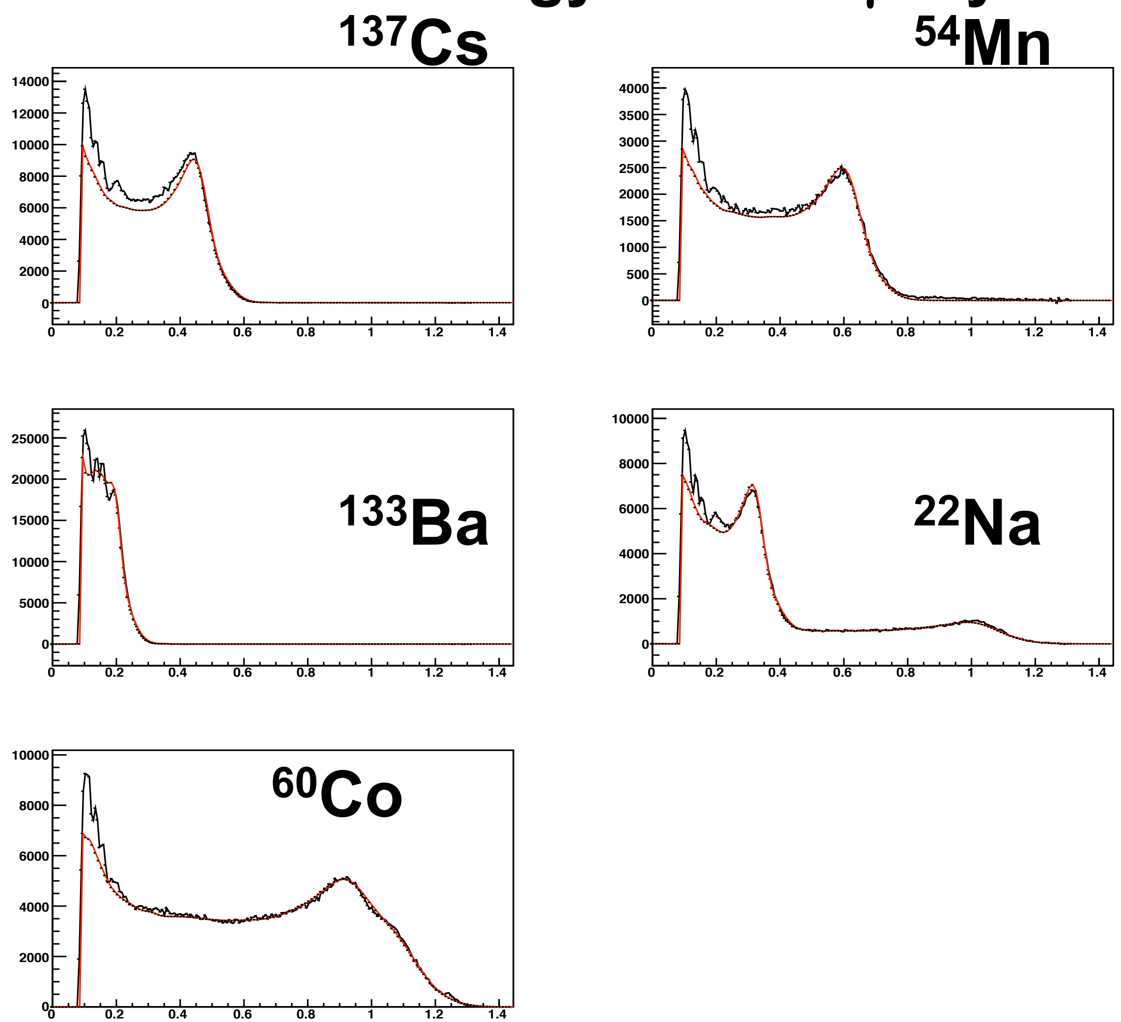


$$E_n = E_{n'} - E_{recoil}$$

$$E_{n'} = \frac{1}{2} m \left(\frac{d}{\Delta t} \right)^2$$

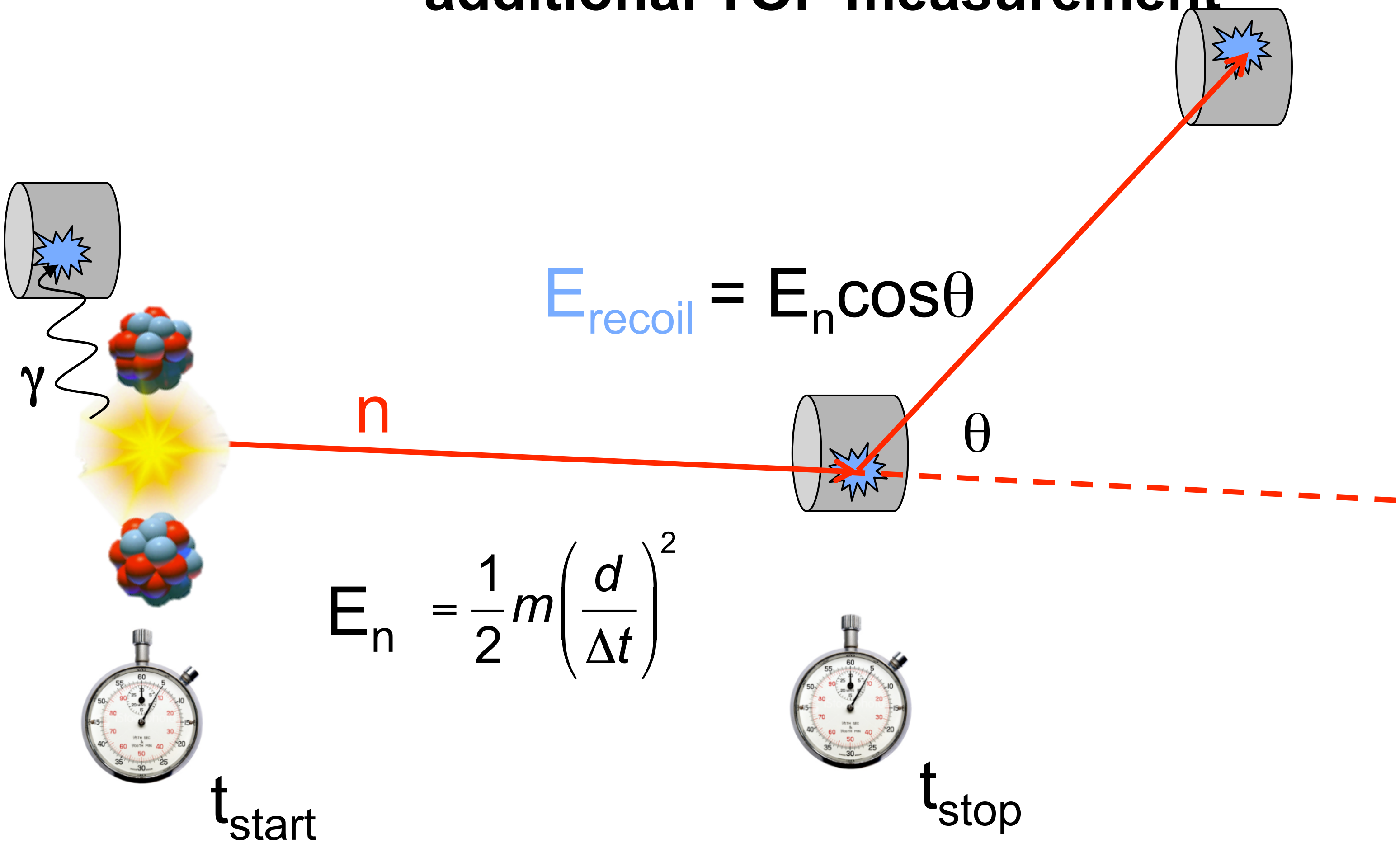
Required Calibrations

- E_{recoil}: Electron Energy Scale – γ-ray sources



Required Calibrations

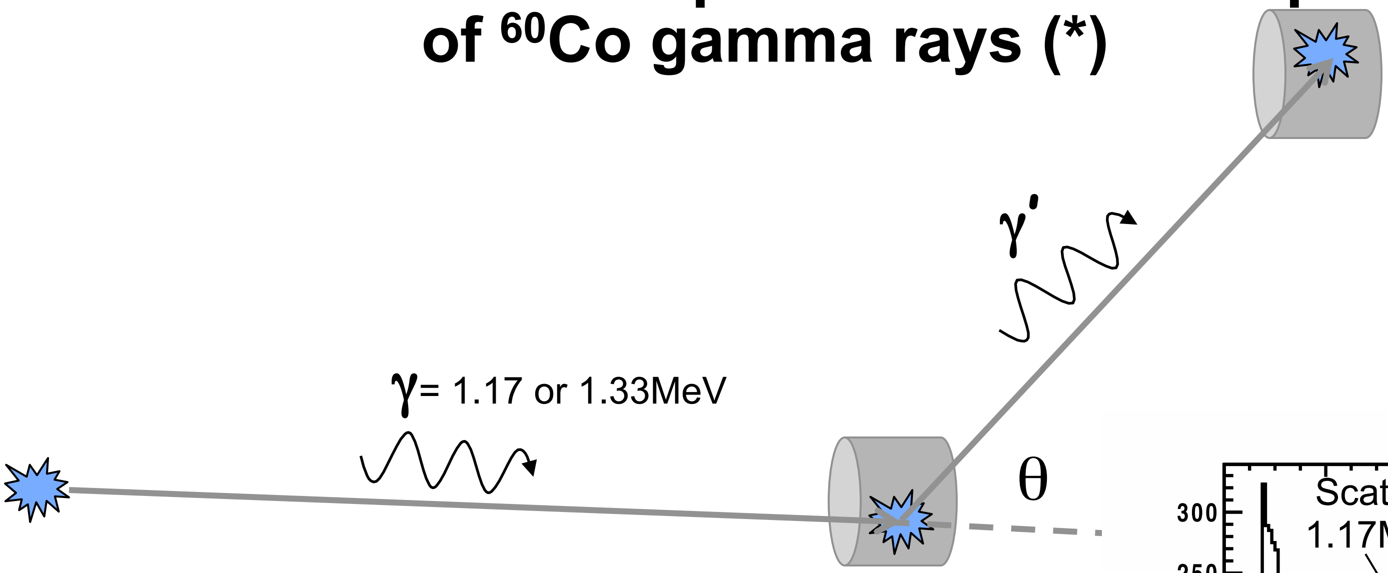
- E_{recoil}: **Proton light yield**
  Dedicated one-off calibration using additional TOF measurement



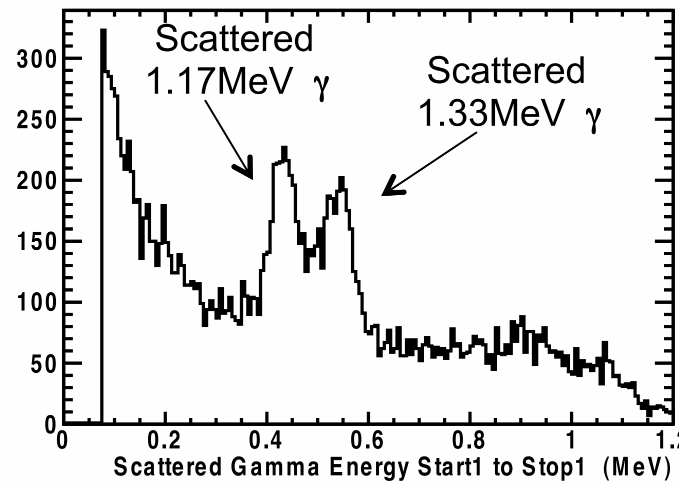
Required Calibrations

- E_{recoil}: **Proton light yield**

  Precisely measure scattering angle for each detector pair in-situ via Compton Scattering of ^{60}Co gamma rays (*)



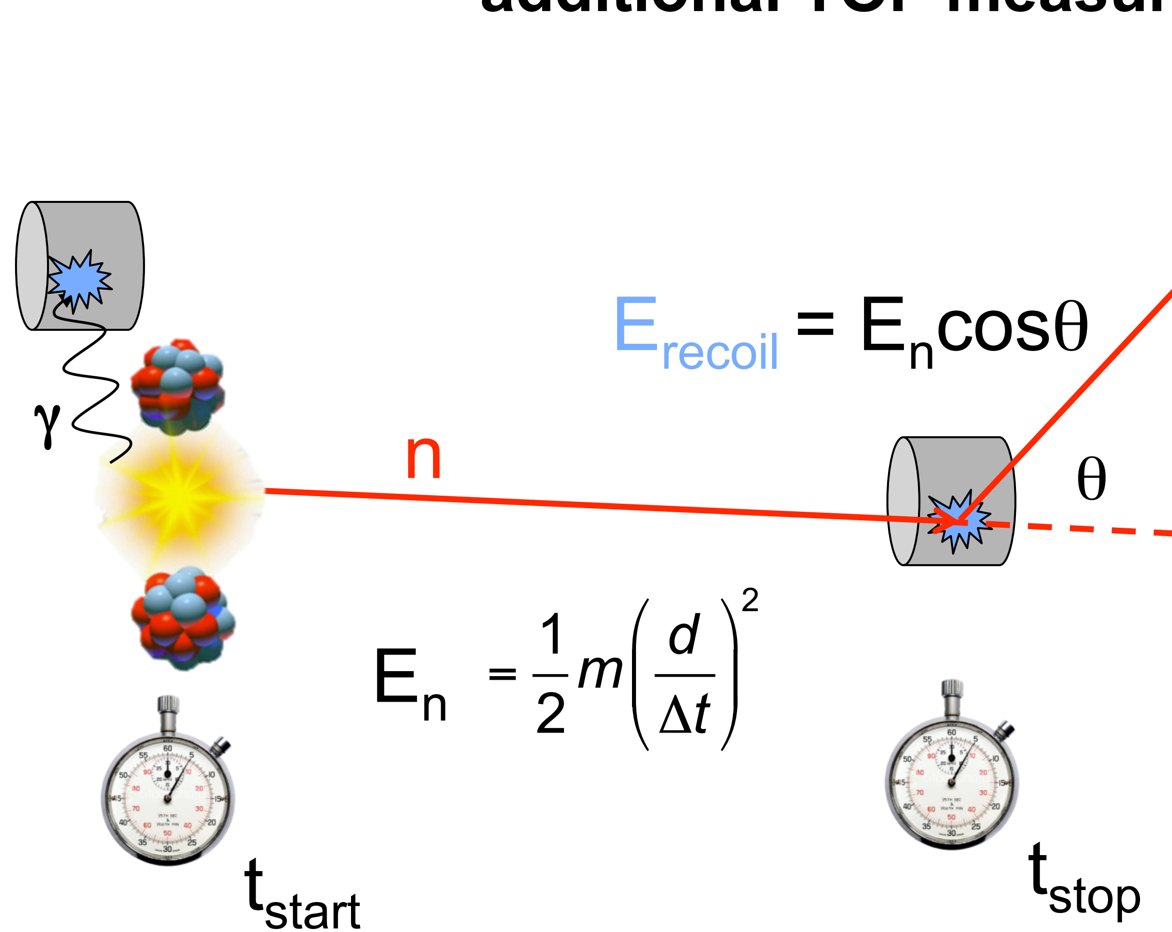
$$\lambda' - \lambda = \frac{h}{m_e c}(1 - Cos\,\theta)$$



(*) only important for proton light yield calibration, not required for general spectroscopy

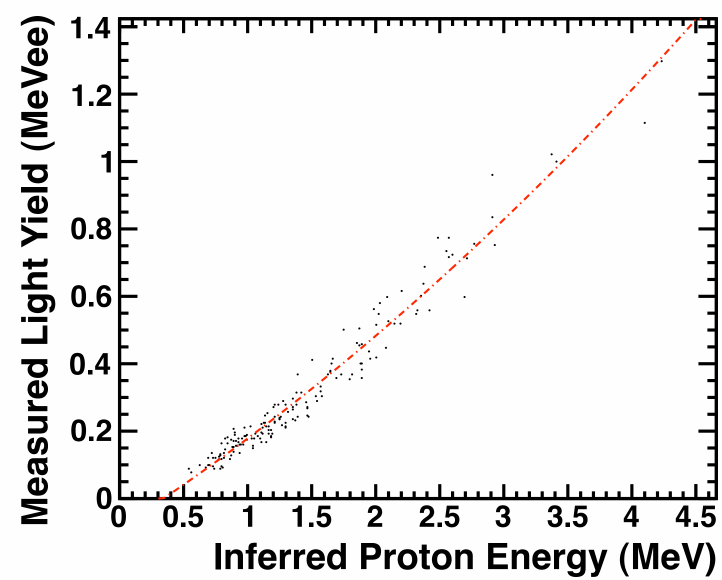
Required Calibrations

- E_{recoil}: Proton light yield
  Dedicated one-off calibration using additional TOF measurement



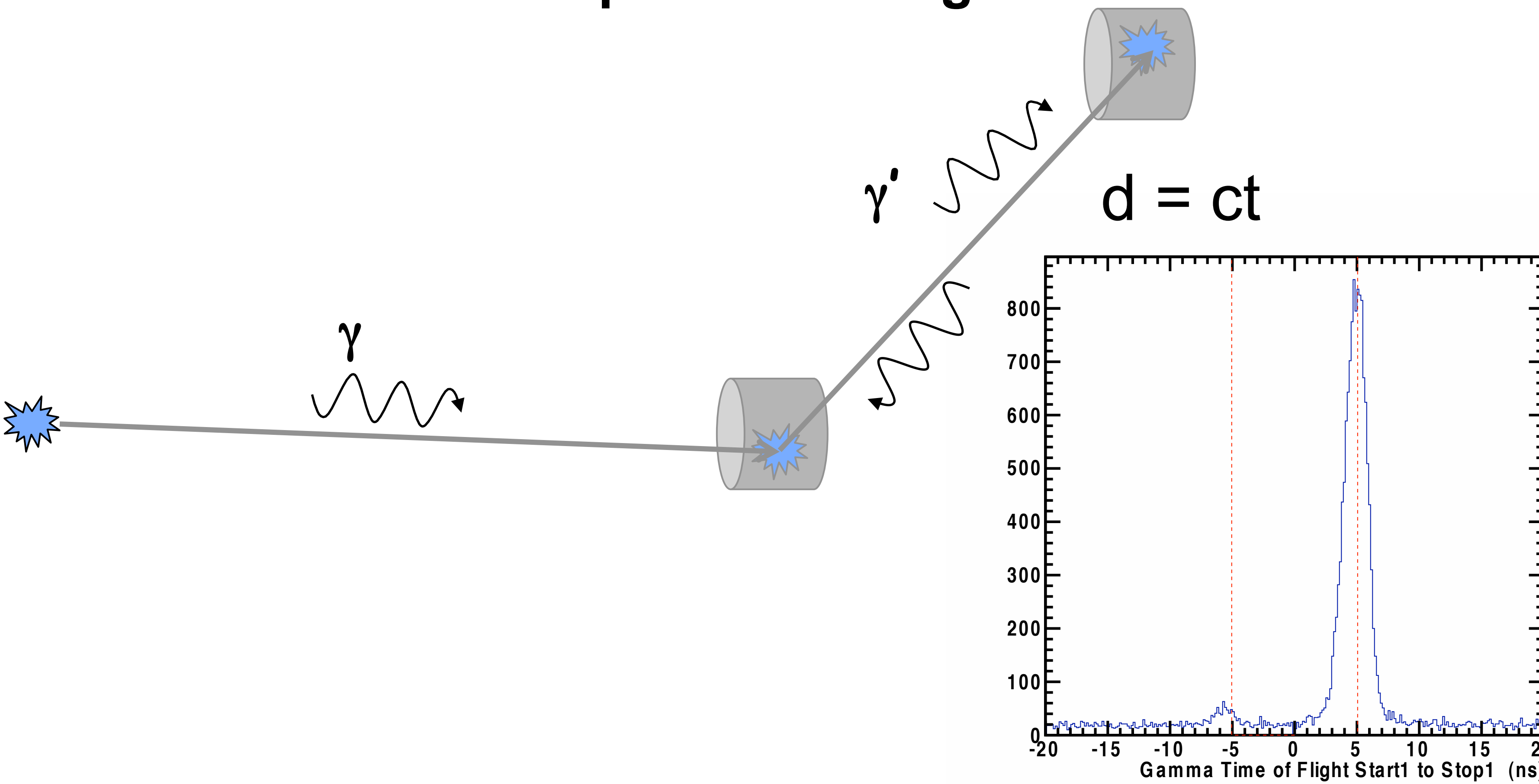
$$E_{recoil} = E_n \cos\theta$$

$$E_n = \frac{1}{2} m \left(\frac{d}{\Delta t} \right)^2$$



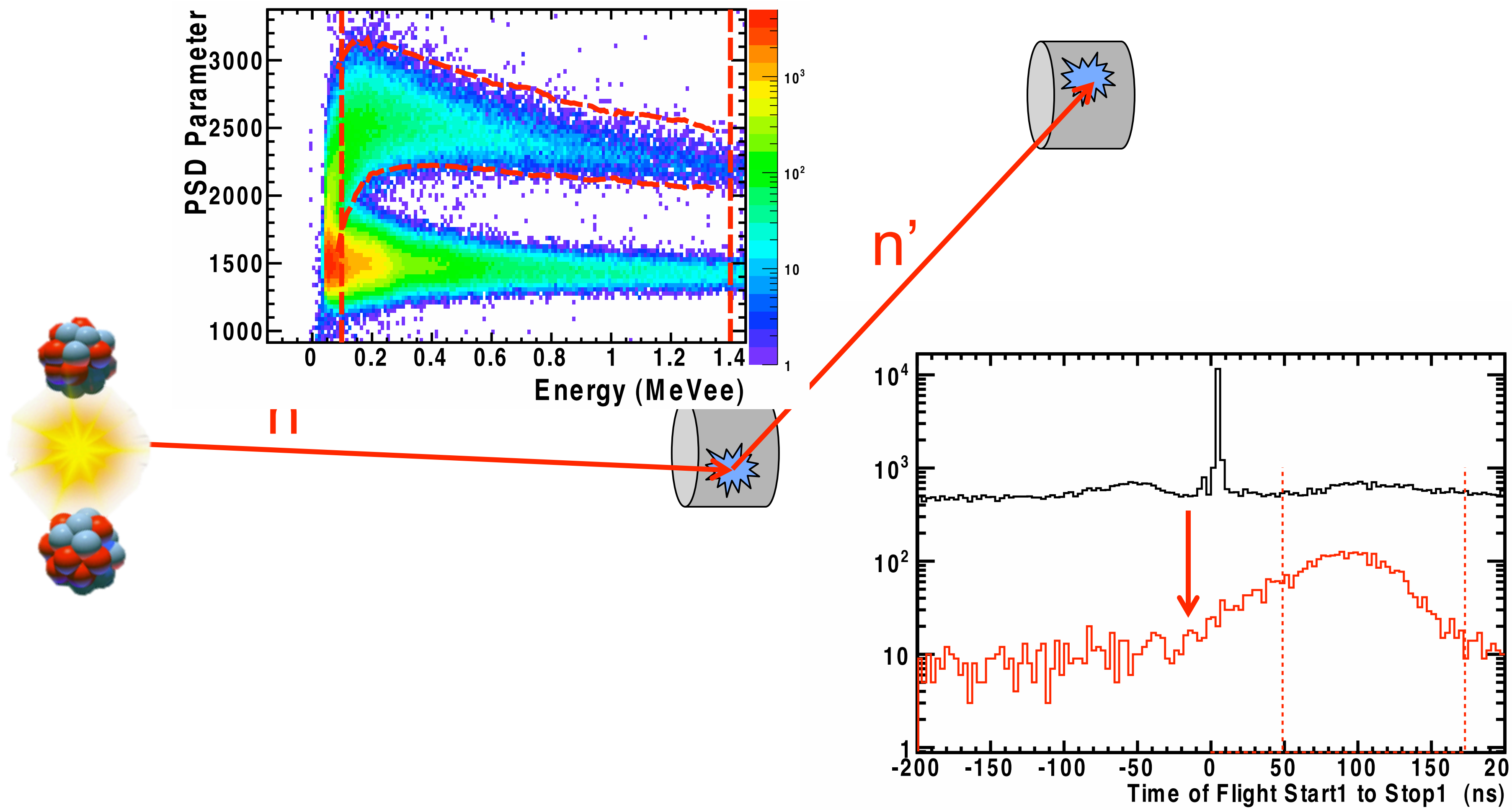
Required Calibrations

- $E_{n'}$: Start-Stop Timing - TDC cal via precision pulser
  Start-Stop Distance – gamma TOF



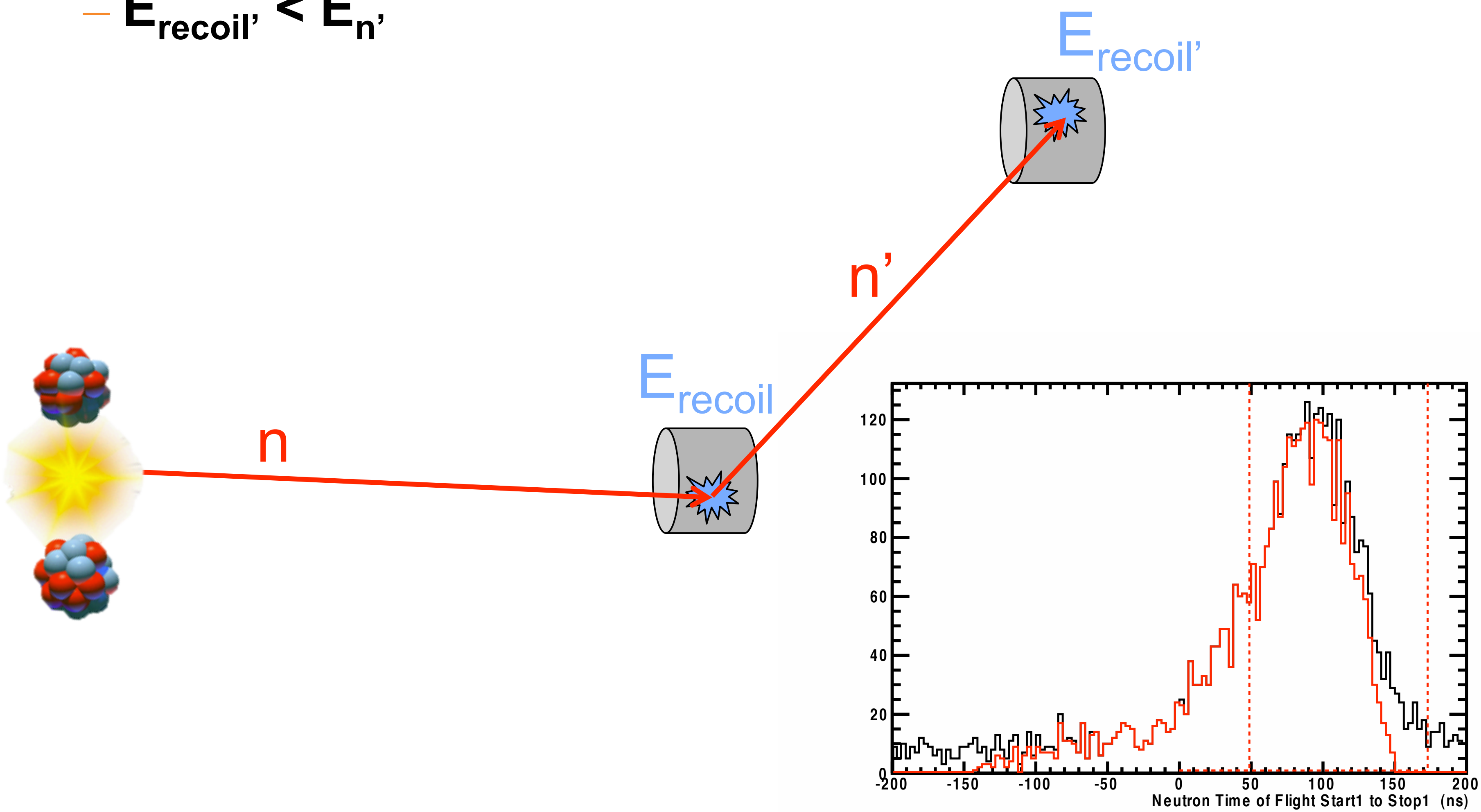
Spectroscopy Analysis

- **Event Selection:**
  - **Neutron Recoil in both detectors**



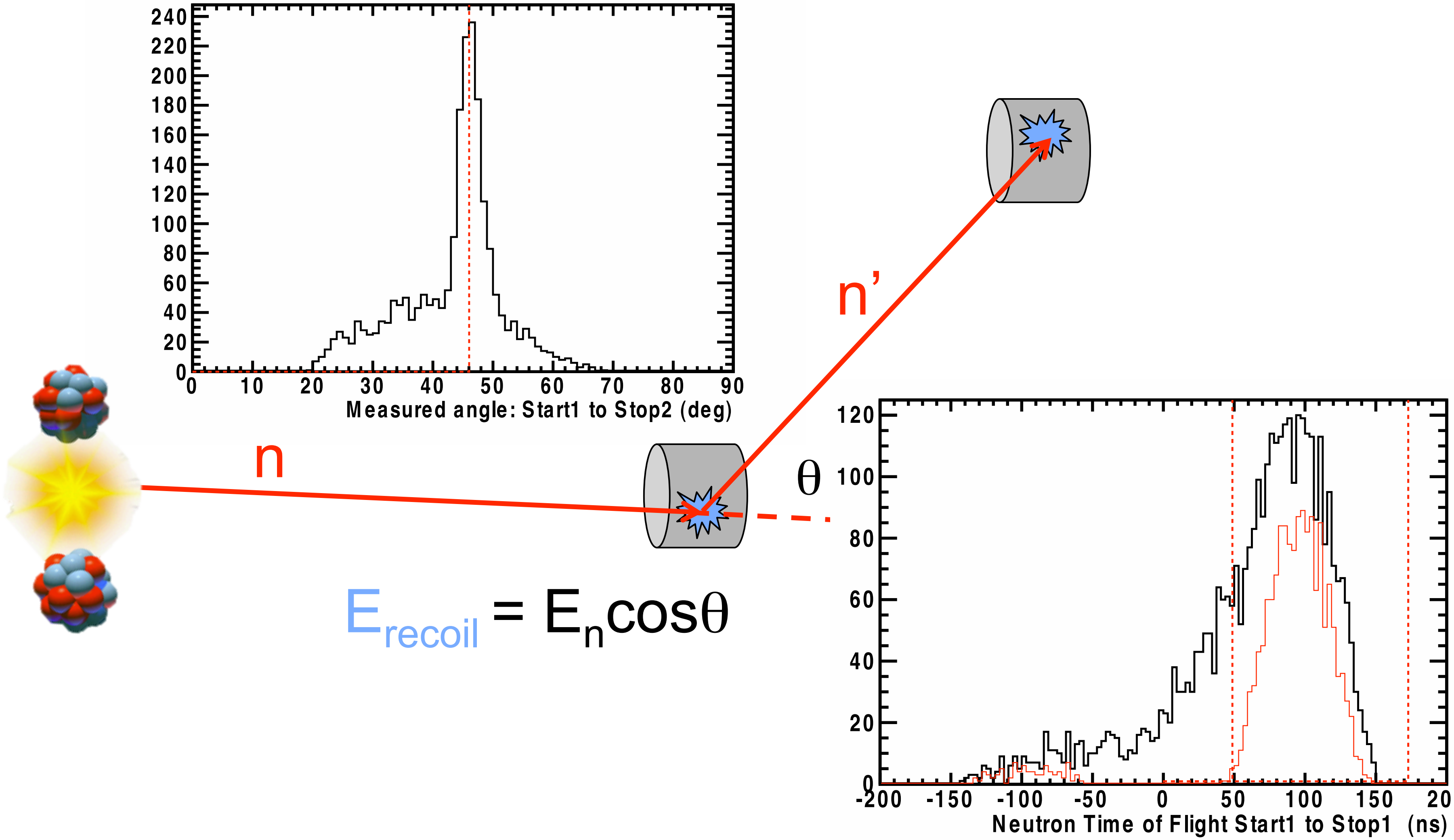
Spectroscopy Analysis

- **Event Selection:**
  - $E_{recoil'} < E_{n'}$



Spectroscopy Analysis

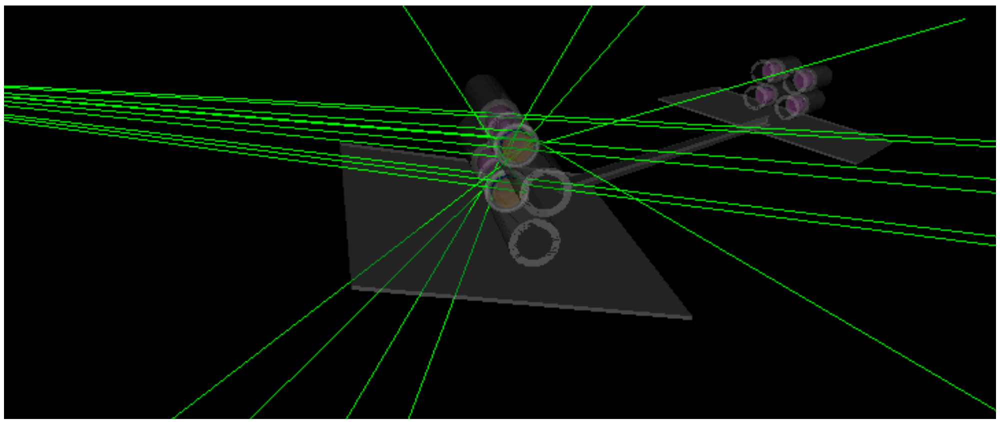
- **Event Selection: - Measured Angle correct**

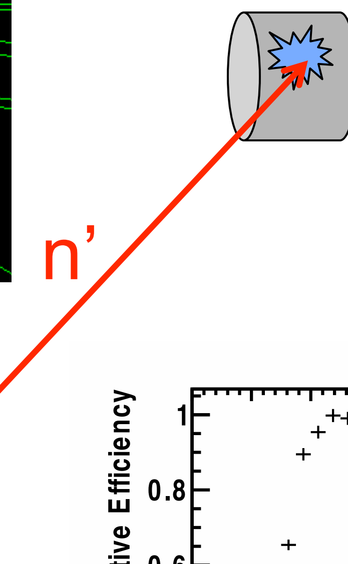


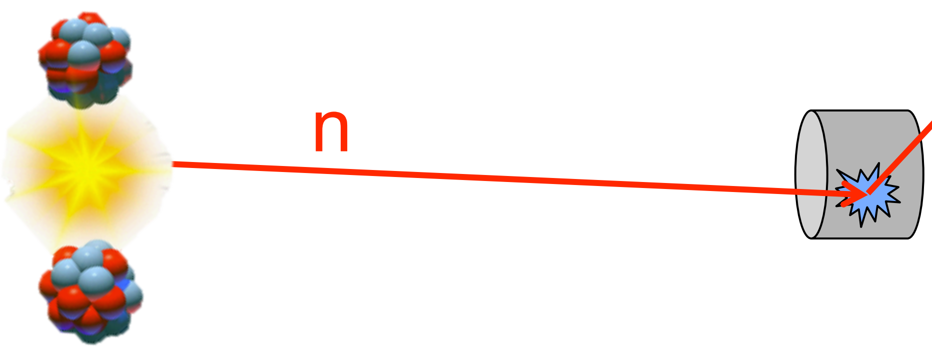
$$E_{recoil} = E_n \cos\theta$$

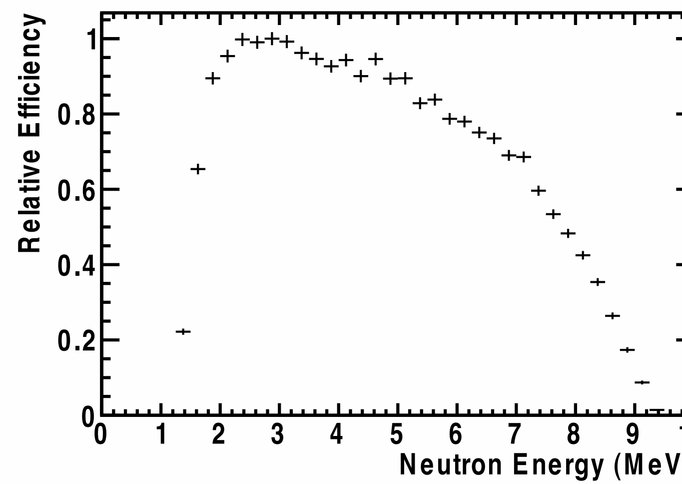
Spectroscopy Analysis

- **Relative Efficiency from GEANT4 Simulation**

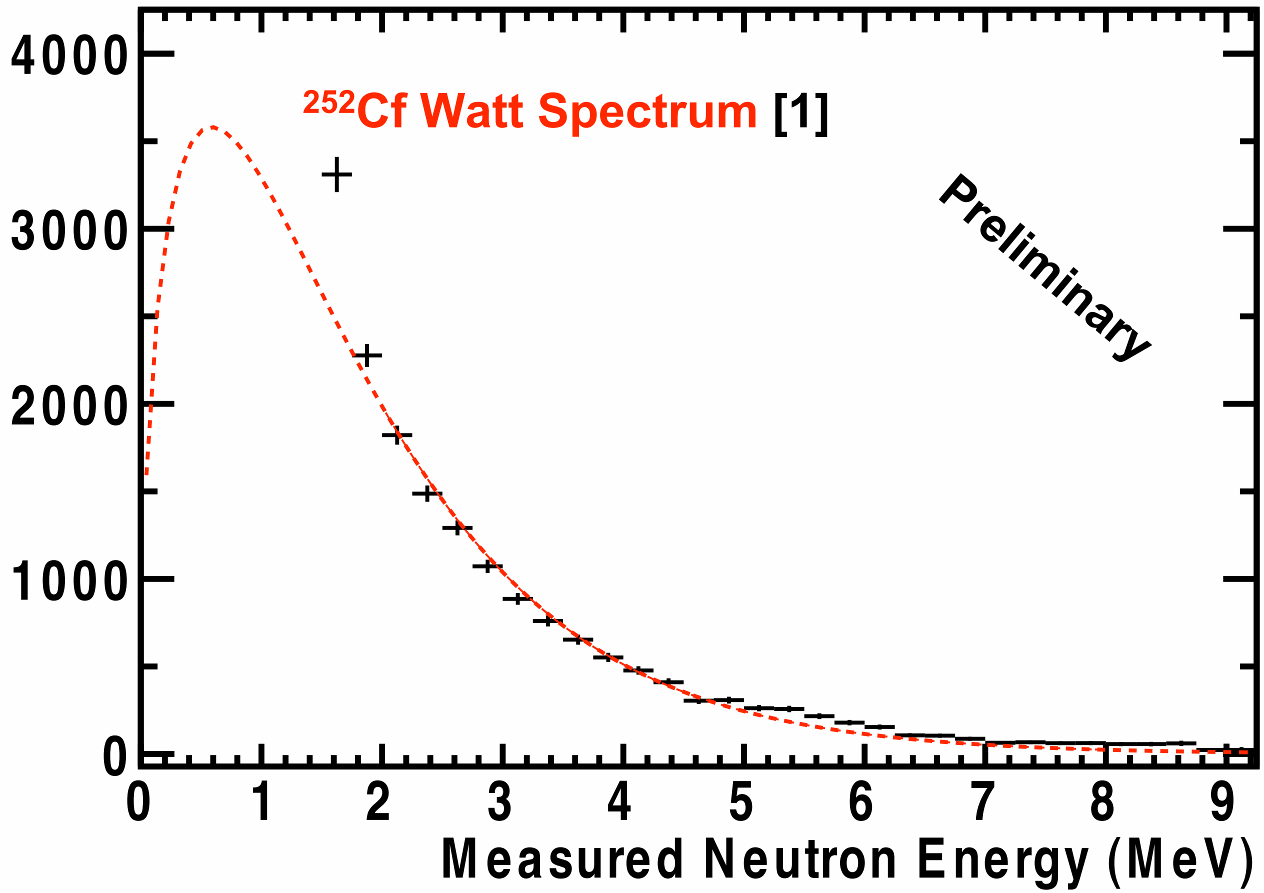








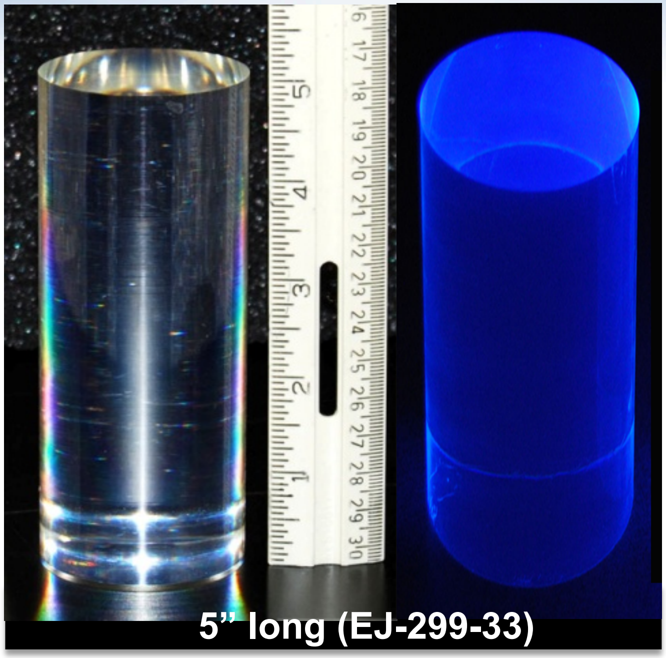
Comparison with RoSpec Data

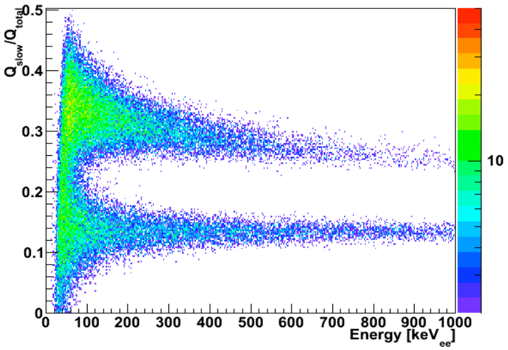


[1] F. H. Froehner, Nucl. Sci. Eng., 106 (1990) 345

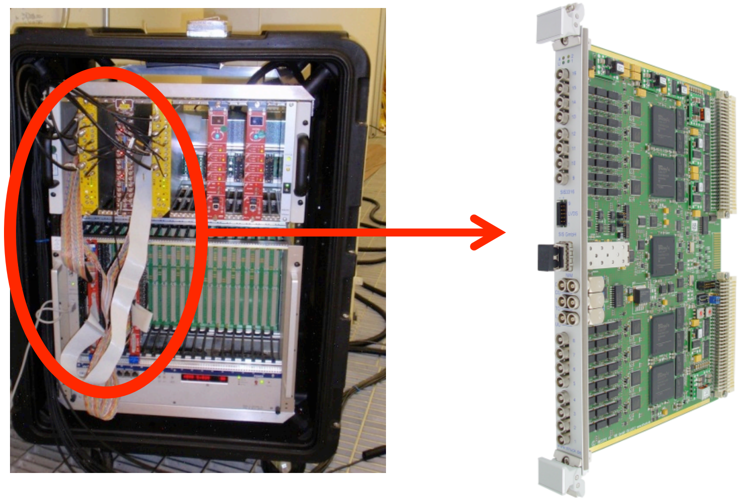
Possible Upgrades

- Plastic PSD organic scintillators
  - Developed at LLNL
  - Now available commercially as EJ-299-33 from Eljen Technologies



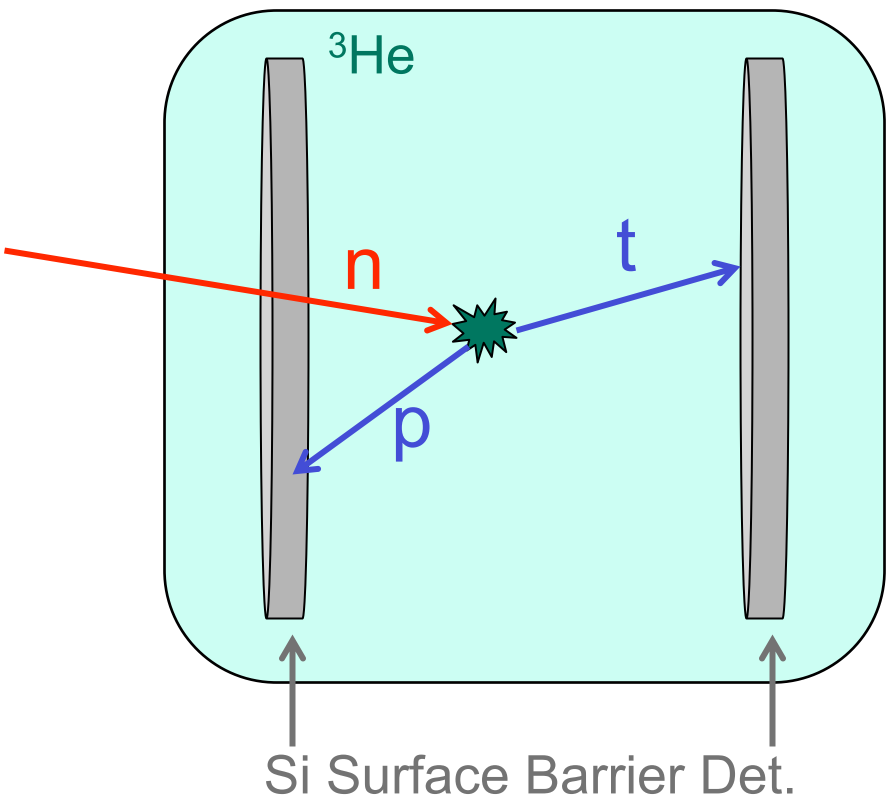


- All digital, single module readout (recoil energy and TOF)



Direct Measurements at Lower Energies?

- Hybrid nTOF limited to ~> 1MeV by LS light yield
- Lower energies will require use of capture reaction (i.e ^{3}He) to provide means of detection
- Concept investigated: ^{3}He/^{4}He/Solid-State Sandwich Spectrometer
- Measure Gas Ionization (e.g. ^{3}He tube) + Si detector signal



- Excellent background rejection from triple coinc. requirement
- Previously demonstrated:

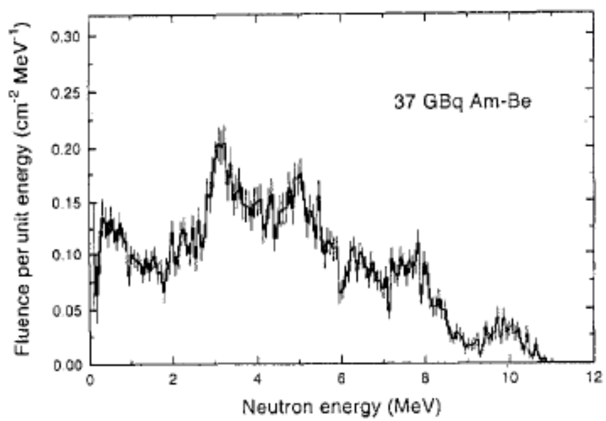
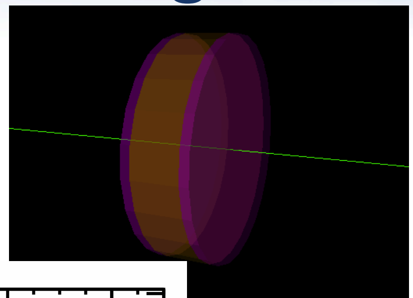


Fig. 5. Measured neutron energy spectrum from the 37 GBq Am–Be neutron source normalized to unit fluence, (uncertainties are due to counting statistics only).

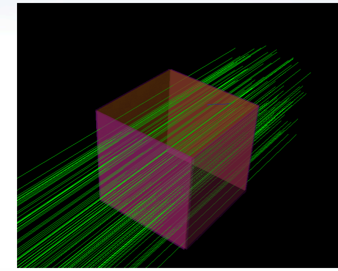
Marsh, et al, NIM A, 366 (1995) 340

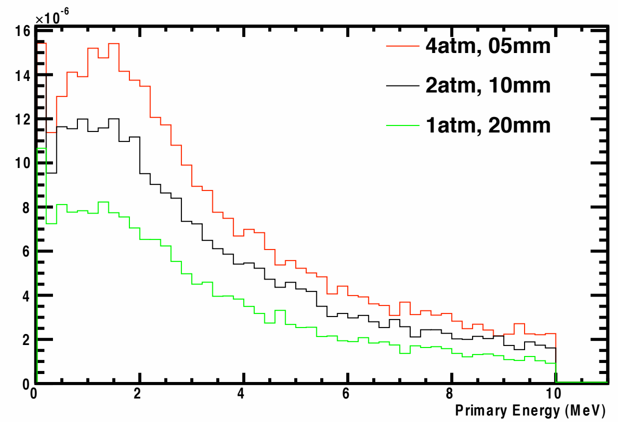
Simulation Design Studies for 3He/Si detector

- 5cm Silicon Disks
  - Vary pressure, separation

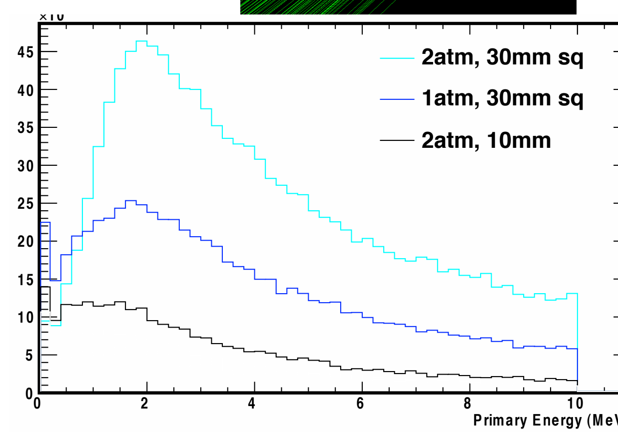


- 3cm Silicon Squares
  - Greater efficiency, complexity

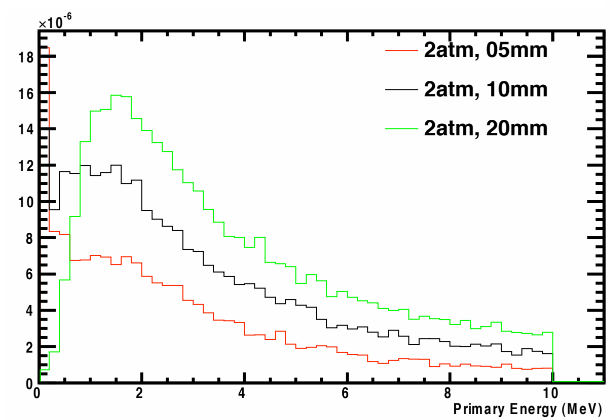




- With constant separation, 2atm pressure, gives most uniform response



- With constant # of target atoms, smaller plane separation give greatest eff.



- Square geometry gives superior performance

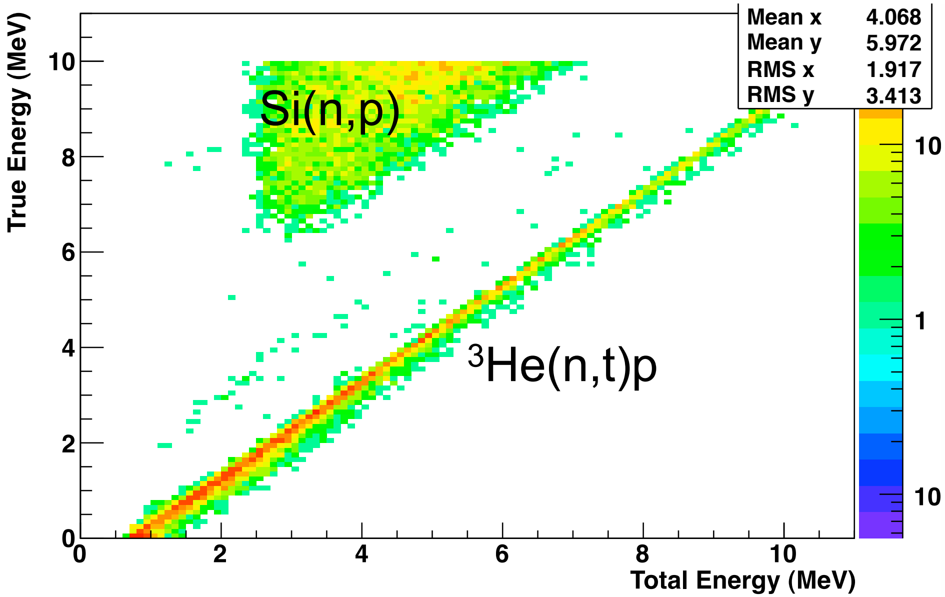
- Efficiency: ~2e-5 per incident neutron

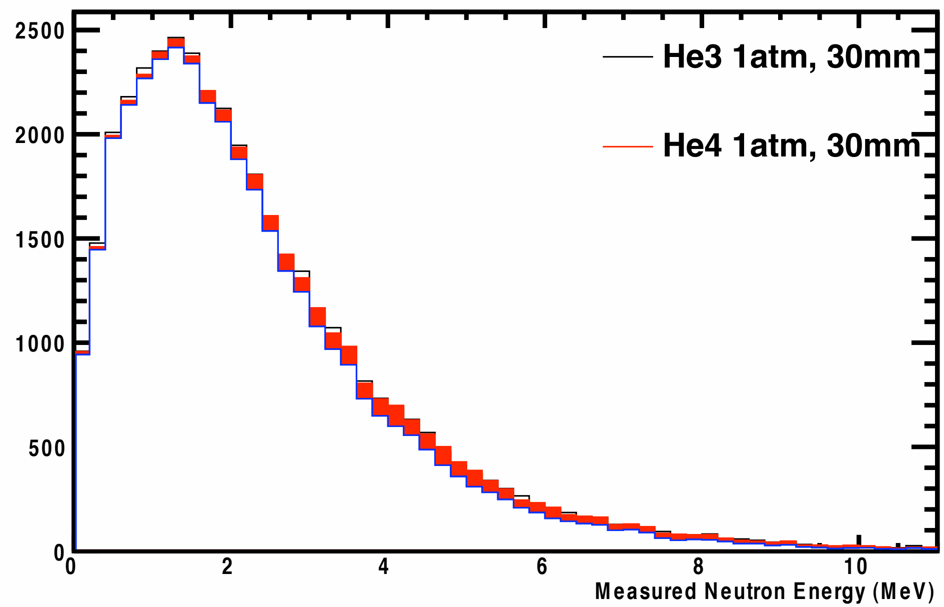
Resolution: ~ 100-200 keV

- Detection rate 0.5m from 1e7 n/s source: 0.5 Hz

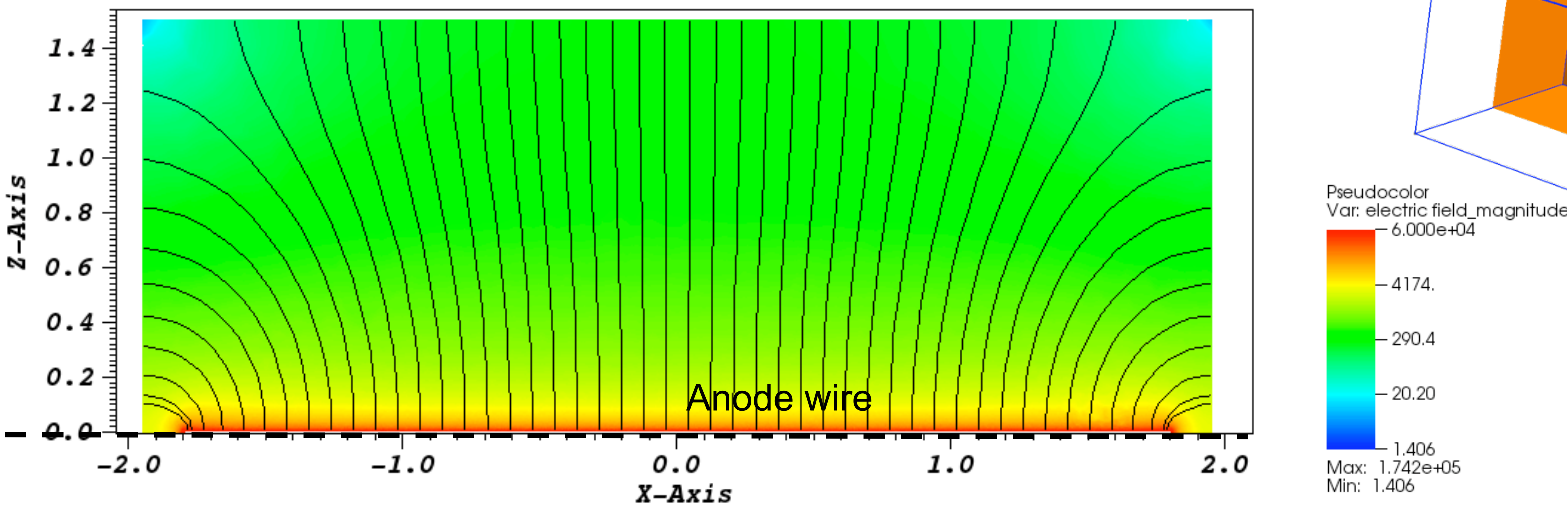
Si(n,p) Background

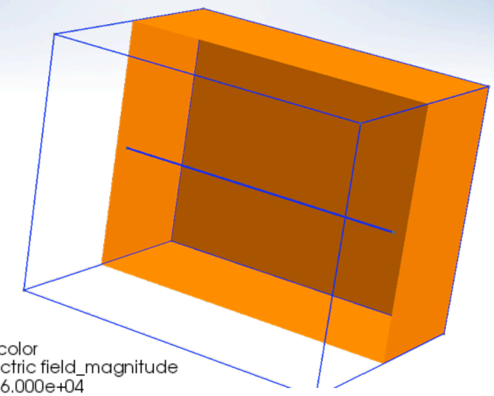
- This approach has intrinsic background due to Si reactions – can be subtracted via parallel measurement with ^{4}He



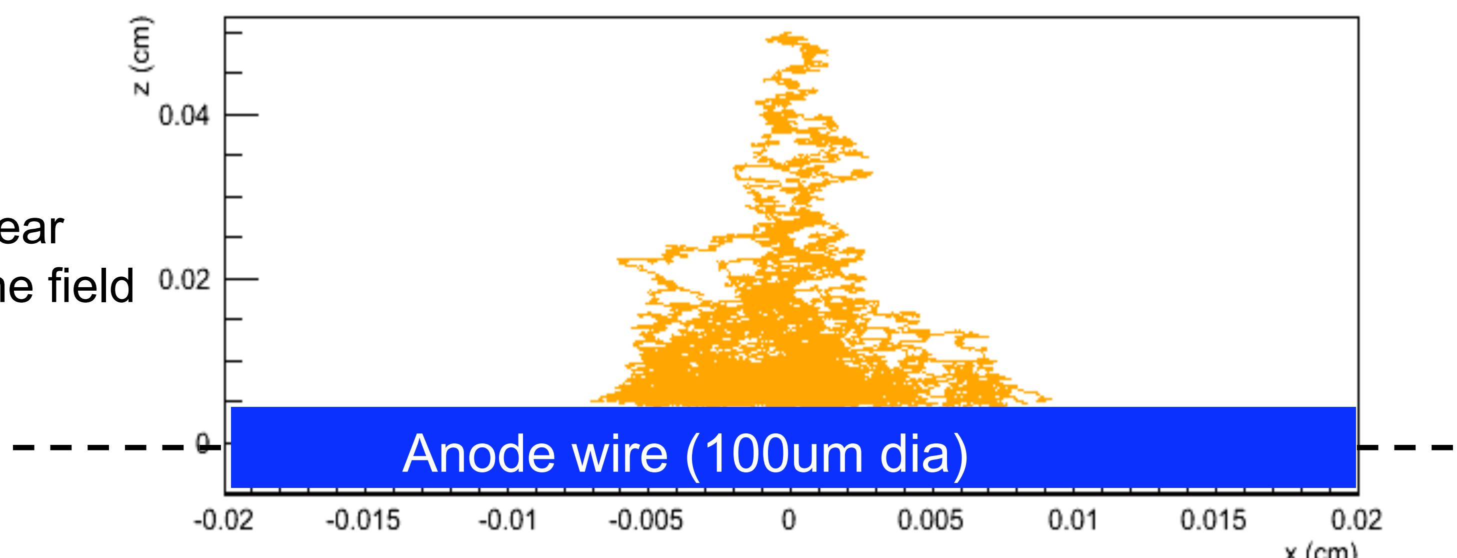


Electrostatics Simulations



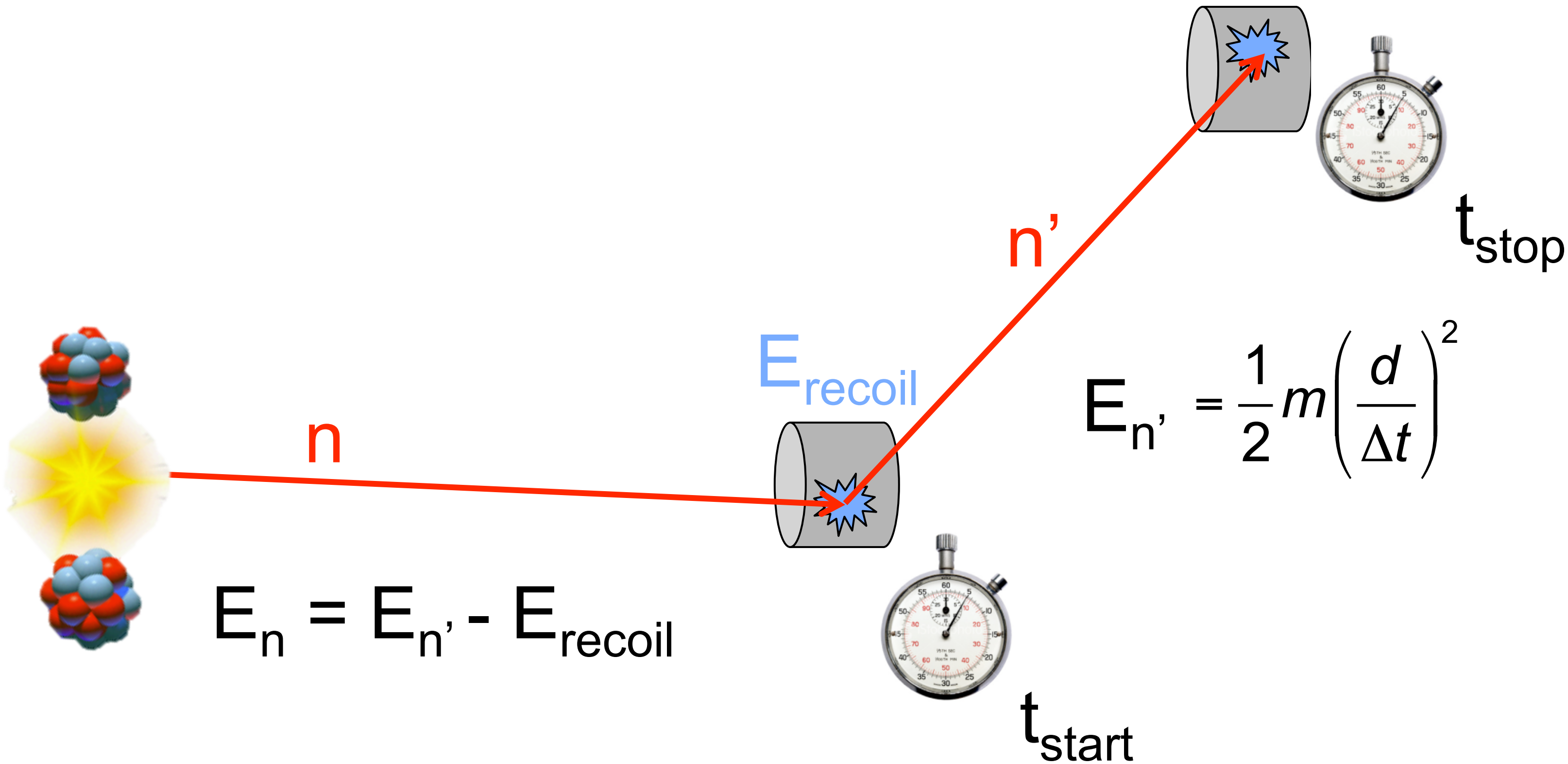


Example of avalanche near the wire in the field above



Conclusions

- We have investigated several direct neutron spectroscopy techniques
- A hybrid neutron Time-of-Flight system based on Liquid Scintillator detectors has been built and characterized
  - provides direct measure above ~> 1 MeV, with a simple Gaussian response function
- An optimized conceptual design has been produced for a 3He/Si system that would have sensitivity down to thermal energies and 100-200keV resolution across the fission energy spectrum

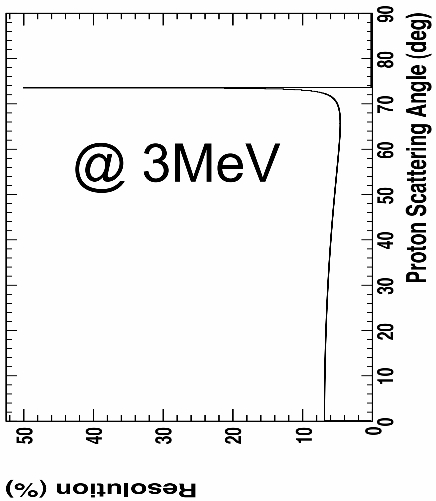


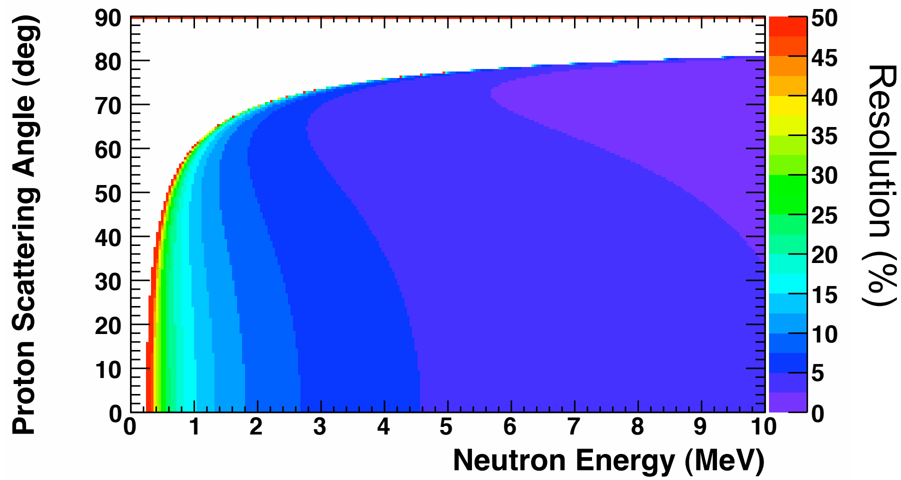
$$E_{n'} = \frac{1}{2} m \left(\frac{d}{\Delta t} \right)^2$$

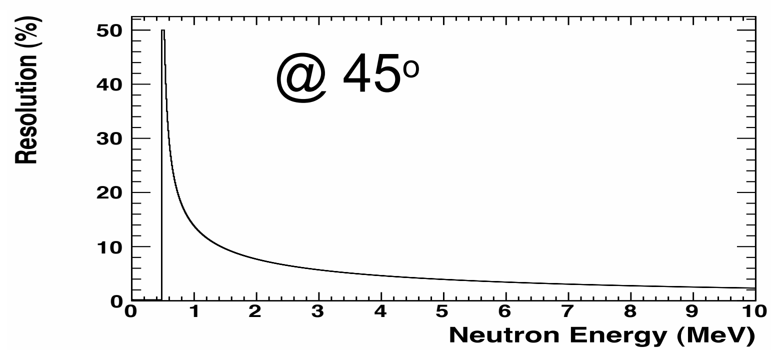
$$E_n = E_{n'} - E_{recoil}$$

Design Considerations

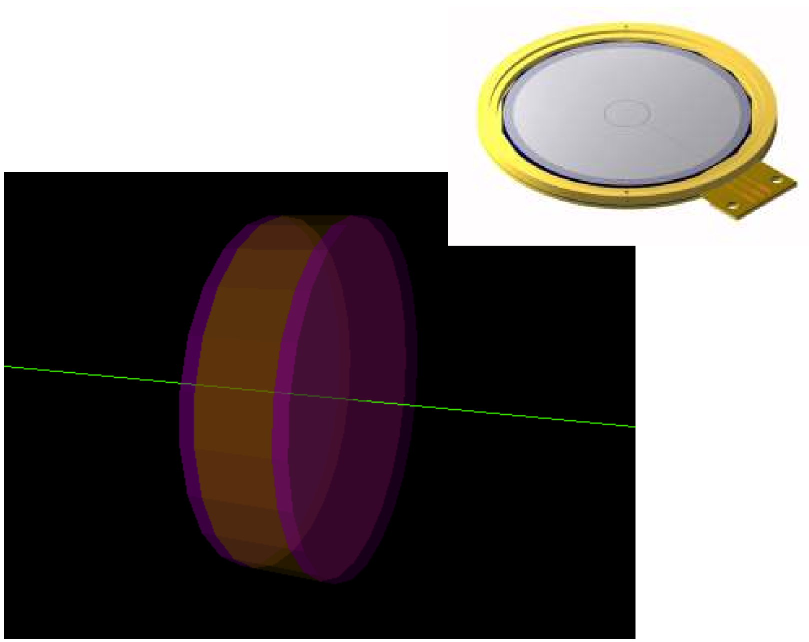
- User selected scattering angle affects efficiency and resolution: 45^o a good compromise

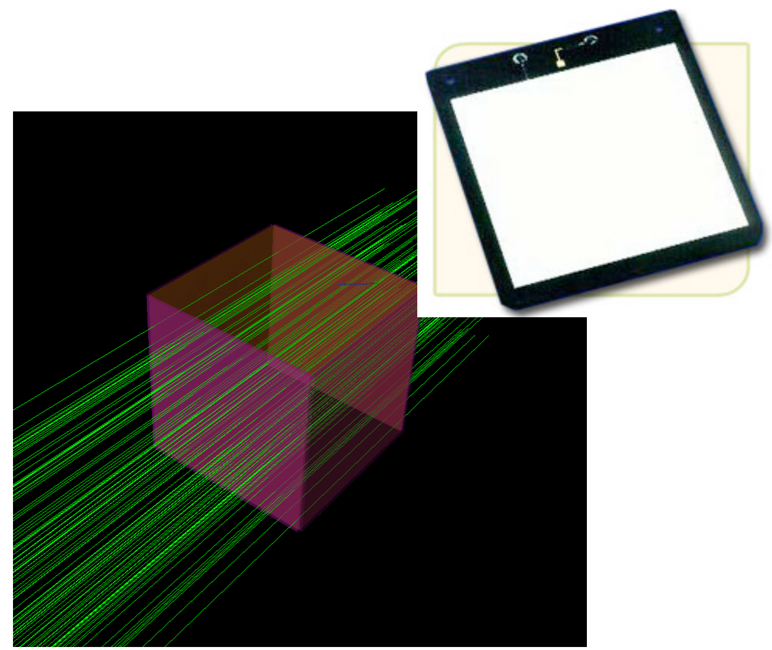






COTS Silicon Detectors





Helium-3 Supply?

- Provided by DOE
- Cost ~ 10k$ per lecturer bottle
- Need only 1-2 STP liters

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Supply and Demand of Helium-3 (^3He)

Please click here to request a quote for ^{3}He. Note: you will be redirected to the Linde website where you will need to register before completing a quote request.

The need for ^{3}He in the United States is outpacing production

The Department of Energy (DOE) has supplied isotopes and isotope-related services to the Nation and to foreign countries for

IER 184
Thermal/Epithermal eXperiments (TEX)
CED-1 Preliminary Design

Catherine Percher and Dave Heinrichs
Lawrence Livermore National Laboratory

TEX History

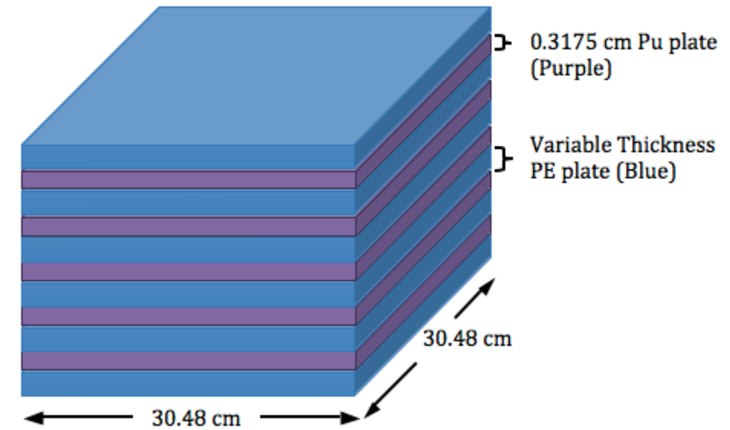
- TEX Feasibility Meeting
  - July 2011 at Sandia National Laboratories, Albuquerque, NM
  - Representatives from US, UK, and France

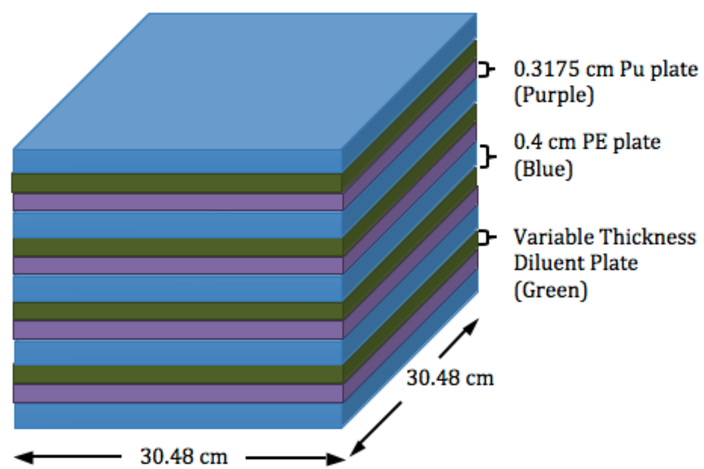
- Consensus prioritization of nuclear data needs (in order):
  - ^{239}Pu, ^{240}Pu, ^{238}U, ^{235}U, Temperature variations, Water density variations, Steel, Lead (reflection), Hafnium, Tantalum, Tungsten, Nickel, Molybdenum, Chromium, Manganese, Copper, Vanadium, Titanium, and Concrete (reflection, characterization, and water content).

- Intermediate Spectrum
  - Limited Data (2.1% of ICSBEP Benchmarks)
  - Fissile/Diluents

CED-1 Accomplishments

- Identified NCSP assets and facilities that achieve intermediate spectrum
  - HEU Jemima Plates
  - Pu ZPPR Plates
- Identified Security Category III/IV alternative
  - U(19.9)- 10 Mo
- Assembly design is easily modified to include various diluents
  - Fe, Hf, Ta, Ni, Cu, Mo, W
- Assembly design includes similar, clean experiments spanning thermal to fast energy range
- Sensitivity analysis used to ensure adequate testing of the cross section over the intermediate energy range





Pu ZPPR Chosen For CED-2, Final Design

- Can create fast, intermediate, or thermal assemblies by stacking polyethylene and fuel (see graph below)
- Highest sensitivities
- ^{239}Pu and ^{240}Pu were number one and two nuclear data need
- Highest priority diluents, Fe, Hf, and Ta